The Journal of Thoracic Surgery

VOL. 8 FEBRUARY, 1939 NO. 3

Original Communications

HEART WOUNDS

A REPORT OF SEVENTEEN PATIENTS OPERATED UPON IN THE MEDICAL COLLEGE OF VIRGINIA HOSPITALS AND A DISCUSSION OF THE TREATMENT AND PROGNOSIS

I. A. BIGGER, M.D.
RICHMOND, VA.

IN THIS country the number of operations for heart wounds has increased rapidly during the past few years. Ramsdell[1] was able to find reports of 428 such cases before January 1, 1932, only fifty-five of them from this country. I recently mailed a questionnaire to 427 surgeons, the members of the American Association for Thoracic Surgery, of the American Surgical Association, and of the Southern Surgical Association. Three hundred and three replies were received, and from these it was found that forty-seven surgeons had operated upon 124 patients for heart wounds. These cases along with the 17 which we are reporting make a total of 141 cases. One surgeon (Elkin) has operated upon 23 of these patients during the past eight years.

In twelve of our seventeen cases there were simple penetrating wounds of the heart cavities or the lumina of the intrapericardial portion of the great vessels. In one, a stab wound, the blade passed through the right ventricle and entered the posterior wall but did not penetrate it completely. In another, a penetrating wound of the left ventricle, the left anterior descending coronary artery was divided. Eight of these patients recovered and four died. In two others the wounds passed through both the anterior and posterior walls. In the first one a bullet destroyed a rather large segment of the left border of the heart, including the anterior, left lateral, and posterior walls of the left ventricle. In the

Read at the Twenty-First Annual Meeting of the American Association for Thoracic Surgery at Atlanta, Ga., April 4, 5, and 6, 1938.

other case a knife blade passed through the extreme upper portion of the anterior wall of the right ventricle, between the pulmonary valves (without injuring them), and out through the posterolateral wall of the pulmonary artery. Both of these patients died, the first from hemorrhage and the other from bilateral pulmonary atelectasis.

In three cases the wounds were nonpenetrating, but two of them had divided moderate-sized branches of the coronary arteries, which resulted in tamponade. The third had a superficial bullet wound of the wall of the right ventricle with only moderate hemorrhage. At that time the value of fluoroscopic examination was not appreciated, so the wound was explored even though the signs of tamponade were not clear-cut. All three of these patients recovered. The patient with the extensive bullet wound of the left ventricle was bleeding freely into the left pleural cavity and showed the picture of massive internal hemorrhage rather than cardiac tamponade. The remaining fifteen patients all showed more or less typical signs of tamponade.

TREATMENT

When a patient is admitted to the Medical College of Virginia Hospitals with signs and symptoms suggesting a wound of the heart, he is placed in moderate Trendelenburg position, given morphine and atropine and, if in profound collapse, is given 5 minims of adrenalin hypodermically; 10 to 15 minims of adrenalin are added to the venoclysis fluid, which is administered slowly. The blood pressure is taken frequently, the general appearance is carefully noted, and the superficial cervical veins are inspected. The latter observation should be made with the patient in the horizontal position. The thorax is examined, and an attempt is made to discover if there is pneumothorax, hemothorax, or a combination of the two. The cardiac area is carefully percussed and auscultated. In two instances, in which there was free communication with the left pleural cavity, we have noted a characteristic splashing or churning sound with each heartbeat. If this sound is present in association with massive hemorrhage, immediate operation is indicated; but if there is only a small amount of blood in the pleural cavity and there are no signs of tamponade, conservative treatment is continued.

When there are signs of marked tamponade and the blood pressure does not rise above shock level, the patient is operated upon without further delay. If there is any doubt as to the diagnosis and if the patient's condition is not too serious, further studies are made, especially frequent determinations of the arterial and venous pressure and fluoroscopy. The diagnosis of tamponade can be made with certainty by the use of the fluoroscope, and this in conjunction with the arterial and venous pressure determinations will give an accurate idea of the degree of tamponade.

In the past we have been inclined to operate upon all patients with signs of tamponade or with signs of cardiac injury and moderate or massive intrapleural hemorrhage. As a result of our experience and a review of the literature we now believe that patients with heart wounds should be operated upon promptly if the indications are clear and urgent, but if the indications are not urgent some form of conservative treatment should be considered.

For purposes of study we suggest that patients with wounds of the heart be divided into four groups, a plan somewhat similar to that recommended by Mayer.[2] Patients with evidence of cardiac injury but without tamponade or massive intrapleural hemorrhage are placed in Group I. Patients with tamponade but who show a satisfactory response to conservative measures, with a return of the arterial pressure to near normal, are placed in Group II; while those who do not show a satisfactory response, with a persistent low blood pressure, are placed in Group III. Patients with penetrating wounds of the heart with free bleeding into the pleura constitute Group IV.

The following four cases are presented to illustrate the problems encountered and the plans for handling each of these four groups.

CASE 1.—G. T.,* a colored man 22 years of age, was admitted to the St. Philip Hospital on Nov. 24, 1930. He had been shot through the left arm, the left side of the chest, and the left thigh a short time before admission. His blood pressure was 95 systolic, 60 diastolic, but a short time later the systolic pressure dropped to 90 and remained at about that level for several hours, then rose gradually to 120. Examination of the thorax showed a bullet wound in the left fourth intercostal space about ¾ inch within the nipple line. The left pleural cavity contained a considerable quantity of blood and some air.

The patient was treated conservatively, and about six hours after admission examination of the cardiac area revealed a splashing or churning sound which was thought to indicate that there were fluid and air within the pericardial sac. X-ray examination the following day showed air in the pericardial sac and a rather large collection of blood in the left pleural cavity. On the second day after admission the patient was found to have a definite pericardial friction rub, but he did not at any time develop the signs of an appreciable collection of fluid within the pericardial cavity. He made a satisfactory recovery.

Although there was definite evidence of pericardial injury and in all probability a superficial wound of the left ventricular wall in this case, there was neither cardiac tamponade nor excessive hemorrhage, so he was treated conservatively.

CASE 2.—H. B., a colored man 38 years of age, was admitted to the St. Philip Hospital at 3:30 P.M. on March 13, 1938. He had been stabbed in the left second intercostal space, 4 cm. from the sternal border, about fifteen minutes before, and at the time of admission he showed profound circulatory collapse, was pulseless, and blood pressure could not be obtained. The heart sounds at first were inaudible, but later, when his blood pressure had begun to rise following the administration of intravenous fluids and adrenalin, they were audible but were still distant and muffled.

*This case was reported in the Southern M. J., 25: 785, 1932. (Case 1.)

There were no signs of blood or air in the left pleural cavity. The patient's superficial veins were distended and not easily compressed.

After his condition had improved sufficiently, he was moved to the fluoroscopic room, where examination showed no evidence of injury to the left lung or pleura. The pericardial shadow was not appreciably enlarged, but the cardiac pulsations were obscured.

A diagnosis of heart wound with tamponade was made, and the patient was transferred to the operating room. At the time he reached the operating room his blood pressure had risen to 120 systolic, 75 diastolic, and his pulse was of fair quality. He had at that time received about 800 c.c. of 5 per cent glucose solution into his vein.

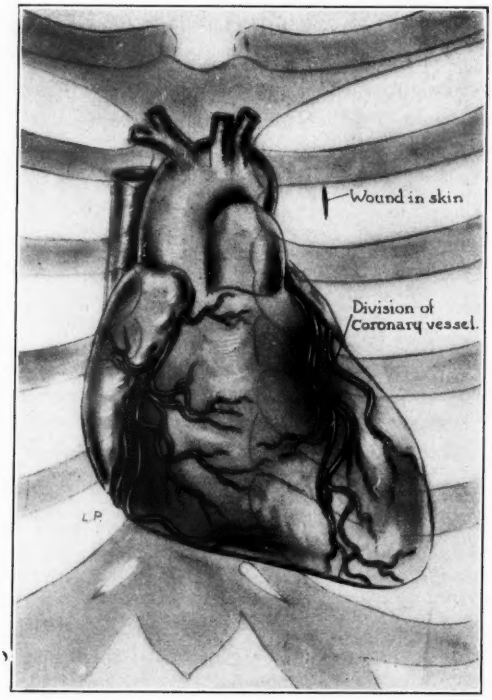


Fig 1.—Showing the location of the division of a branch of the left coronary artery in Case 2.

Under local anesthesia a curved incision was made, extending from the second cartilage just to the left of the sternum, downward and then outward along the lower border of the fourth cartilage nearly to the anterior axillary line. The skin, subcutaneous tissue, fascia, and muscle flap were turned up, and the third and fourth cartilages were exposed. These cartilages were resected subperiosteally, and short segments of the anterior ends of the ribs were removed with them. The triangularis sterni muscle was incised, the internal mammary vessels were exposed, doubly ligated, and divided both above and below. The pleura was stripped away from the pericardium, exposing it over a considerable area. The opening in the pericardium was small and was located beneath the upper border of the fifth cartilage. A small

incision was made at right angles to the mid-portion of the curved incision to expose the anterior end of the fifth cartilage, which was divided and a small segment removed so that it could be retracted downward to give adequate exposure of the wound. The incision in the pericardium was enlarged, and a large quantity of fluid blood escaped under considerable pressure.

Before the pericardium was incised, the patient's venous pressure was 280 mm. of water. Following evacuation of the blood from the pericardial cavity, the venous pressure fell gradually to 160 mm. of water. After the blood had been evacuated it was found that there was no further bleeding, and at first on cursory examination no wound was seen. It was then noted that the patient had a small clot attached to the anterior wall of the heart immediately to the right of the mid-portion of the left descending coronary artery, overlying one of the medium-sized branches of this vessel, which had been divided. The injury was so close to the main stem of the artery that it was felt that if an attempt was made to ligate the injured vessel, it would in all probability be necessary to ligate the main artery. It was decided, therefore, that it would be better to close the operative incision and take the chance of having to reopen it if bleeding and tamponade recurred.

The patient's blood pressure and pulse were watched carefully for the next twenty-four hours, and both remained satisfactory. He had a relatively uneventful convalescence except for several severe attacks of bronchial asthma, which he had had for a number of years. He also developed a mild psychosis which lasted only two or three days.

This patient had all the characteristic findings of cardiac tamponade, including a high venous pressure, distant and muffled heart sounds, and apparent immobility of the cardiac shadow. The arterial pressure was not obtainable on admission and remained low for a considerable time, but just before the operation was begun it had risen to a normal level. It seems likely that this rise in pressure occurred after the bleeding stopped, as it is improbable that the blood pressure would rise to such a level in the presence of increasing intrapericardial pressure. If this is the correct interpretation of this observation, it is of considerable significance. If we have the opportunity to observe a similar case, we plan to proceed with preparations for operation, but after the patient reaches the operating room, a needle will be inserted into the pericardium, the pressure determined, and an attempt made to remove sufficient blood by aspiration to relieve the tamponade, as recommended by Singleton.[3]

A cannula is being made for this purpose, which can be left in place to determine whether or not there is to be a rapid recurrence of the tamponade. Should this recur, operation will proceed, but if there is no recurrence of increased pressure during a period of fifteen to twenty minutes, the cannula will be removed and conservative treatment continued. If the signs of tamponade recur after several hours, aspiration will probably be repeated. In the case presented, it is obvious that one aspiration would have sufficed.

CASE 3.—L. J., a colored man 29 years of age, was admitted to the St. Philip Hospital on Sept. 3, 1936, about fifteen minutes after he had been stabbed in the left side of the chest over the anterior end of the second costal cartilage. According to the history he collapsed almost immediately, and at the time of admission to the hospital he was in profound collapse. Blood pressure could not be determined, and the radial pulse could not be palpated. He was given morphine, gr. ¼; atropine, gr. 1/150; ephedrine, gr. ¾; 5 minims of adrenalin; and 5 per cent glucose solution intravenously. In a short time his condition improved, the pulse became palpable, but only about every third beat came through, and the heart sounds were barely audible.

As soon as his condition had improved sufficiently, he was fluoroscoped, and the pericardial shadow was found to be considerably enlarged and apparently immobile. The shadow was so large that it seemed unlikely that it was due entirely to a hemopericardium, but no history of previous cardiac disease could be obtained from the patient.

A diagnosis of heart wound was made, and immediate operation advised. There was an unfortunate delay in preparing the operating room, and approximately one hour and fifteen minutes elapsed before the operation was begun. During this delay the patient was given fluids slowly into a vein, and his condition remained about the same; but the blood pressure did not rise above the shock level. About the time the operation was started the patient began to have difficulty in breathing and became irrational and difficult to control. Respirations then became irregular, and pulse decreased in volume until it was barely palpable at the wrist.

The third and fourth cartilages were hurriedly resected, the second cartilage was divided at its anterior end, and the pericardium was rapidly exposed and opened. While the cartilages were being resected, the patient ceased to breathe and his pulse could no longer be felt. When the pericardium was opened a very large clot was expelled and this was followed by liquid blood. The heart was found to be stationary but resumed its normal rhythm after gentle massage. There was then profuse bleeding from a wound in the extreme upper portion of the right ventricle. The hemorrhage was partially controlled by applying the index finger of the left hand to the wound, and a suture was passed beneath this finger and tied, being used as a traction suture to control the bleeding partially while the other sutures were placed.

When the operation was started the patient's blood pressure was 80 systolic, 60 diastolic, but dropped to zero, of course, when the heart reached a standstill. After the pericardium was opened and the heart had resumed its rhythm, the systolic pressure rose rapidly to 160, then came down to 130 and remained at approximately this level during the rest of his stay in the operating room. The patient, however, continued to be irrational and was restrained with considerable difficulty after he had been returned to the ward. The mental confusion cleared in about three hours, and his general condition remained satisfactory for eighteen hours. Twenty-four hours after operation his temperature rose to 104.2°, respirations became rapid and irregular, his general condition became progressively worse, and he died about forty hours after operation.

Autopsy showed cardiac hypertrophy, the weight of the heart being 650 gm. The wall of the left ventricle was 2.6 cm. thick and that of the right ventricle 0.7 cm. thick. There was a well-approximated wound on the anterior surface of the upper portion of the right ventricle 2 cm. from the base of the pulmonary artery. The epicardium was covered by a thin fibrinous exudate, while the endocardium was smooth, moist, and glistening except in the region of the wound where there was a very small grayish clot. There was a wound of the endocardium on the posterior wall of the ventricle directly opposite the one of the anterior wall. This was also covered by a small clot. The valves were intact, the myocardium was firm, contracted, and showed no scarring, and the coronary arteries were normal. There were a few scattered lipoid plaques in the ascending portion of the aorta.

The left lung was atelectatic and dark red in color. The right lung was normal, except that it contained a considerable increase of fluid.

The left kidney weighed 250 gm. The major calices, pelvis, and upper 7 cm. of the ureter showed marked dilatation. There was a stricture of the ureter 7 cm. from the hilus of the kidney. The right kidney weighed 190 gm. and showed the same

findings as the left kidney, but to a less marked degree, and there was a stricture of the right ureter 4 cm. from the hilus of the kidney.

The cause of death was apparently atelectasis of the left lung, edema of both lungs, especially the right, and cardiac failure.

This patient presented the classic picture of persistent, circulatory collapse as the result of greatly increased intrapericardial pressure. Unfortunately, the heart came to a complete standstill before a satisfactory exposure had been obtained. Since there was a delay in operating, the intrapericardial pressure should have been temporarily relieved by aspiration, not only to prevent complete circulatory failure, but also to avoid the cerebral changes resulting from prolonged anoxemia. Such changes did occur in this patient and have also been reported by Mayer[2] and others.

CASE 4.—Mrs. R. B.,* a white woman 31 years of age, was admitted to the Memorial Hospital on Jan. 27, 1932, within a few minutes after she had shot herself in the left side of the chest. She was in profound shock at the time of admission. The bullet wound was in the left second intercostal space about 3 inches from the midline, and the wound of exit was in the lower portion of the posterior chest wall just to the left of the midline. The heart sounds were distant, and there was a peculiar splashing or churning sound synchronous with each heartbeat, indicating that both air and blood were present in the pericardial cavity. The left pleural cavity appeared to be almost completely filled with blood.

A definite diagnosis could not be made, but it was thought that the patient had a bullet wound of the heart and a free communication between the pericardial and left pleural cavities.

Operation was carried out immediately and the heart exposed by a transpleural incision. There was a large defect in its left border, the bullet having destroyed portions of the anterior, lateral, and posterior walls of the left ventricle. An attempt was made to close the wound but while this was being done, the patient died, apparently from blood loss.

Few patients with heart wounds as extensive as this one, with a free communication with the pleural cavity, will survive sufficiently long to receive surgical aid, but those with less extensive wounds will occasionally do so, even in the presence of a free communication with the pleura. In such a case, if the heart sounds suggest blood or blood and air in the pericardial cavity and if there is a massive hemorrhage in the pleural cavity, operation should be done immediately. Reinfusion of the blood in the pleural cavity might well prove to be a lifesaving measure.

In a recent case, a wound of the right internal mammary vessels with hemorrhage into the pleura, we reinfused 1000 c.c. of the blood, with striking benefit.

TECHNIQUE OF OPERATION

Anesthesia.—A local anesthetic would seem to be preferable to any of the inhalation anesthetics because we are dealing with patients who are already cyanotic and who are having respiratory difficulty. There are certain practical difficulties, however, which often make it necessary to supplement the local anesthetic. The most important is the fact that these patients are often uncooperative, either from acute alcoholic intoxication or from the effects of prolonged cerebral anoxemia. Under such circumstances, it becomes necessary to control them by the administra-

*This case was reported in Internat. Clin., I, Series 44: 133, 1934. Reported as Case 3.

tion of a general anesthetic. Unfortunately, they are likely to become uncontrollable at the most inopportune time, immediately after the release of the intrapericardial pressure, and for this reason many surgeons do not use local anesthesia. The anesthetics most frequently used are ether and nitrous oxide.

Another objection to local anesthesia is the fact that there is so often an opening in the pleura, or it seems advisable to open the pleura, either for better exposure of the heart or for the purpose of examining the lung. As pointed out by Brunn,[4] quiet, cooperative patients do well with an open pneumothorax, but patients with heart wounds are usually neither quiet nor cooperative. This difficulty may be overcome, however, by the administration of oxygen under low pressure.

If the patient is reasonably cooperative, it seems desirable to use local anesthesia alone or in combination with the administration of oxygen or some of the newer general anesthetics, such as cyclopropane. In our group of seventeen patients the operation was completed under local anesthesia only five times.

Approach.—It seems to be the consensus of opinion that one of the lateral incisions is better than the mid-sternal approach. Theoretically, it is desirable to avoid an open pneumothorax, but it is frequently impossible to do so; furthermore the extrapleural approach is considerably more time consuming than the transpleural one. If there is free bleeding into the pleura or if the incision is to be made to the right of the sternum, the pleura should be opened. If the pleura has apparently not been traversed and if there is no indication for unusual haste, the extrapleural operation should be attempted.

We were able to complete the operation without opening the pleura in only six of the thirteen cases in which this was attempted. Whatever approach is used, it is extremely important to obtain a good exposure before the pericardium is opened.

If the wound is on the anterior surface of the heart, so that it is easily exposed, the maneuver described by Elkin[5] of placing the left index finger over the wound and passing a suture beneath it, is helpful. If the wound is so located that it is difficult to expose it, the apical traction suture recommended by Beck[6] is invaluable.

The pericardium should not be drained externally, but postoperative aspiration may be avoided by closing the pericardial incision with widely spaced interrupted sutures and then leaving an opening in the pleura for internal drainage, as recommended by Griswold.[7]

PROGNOSIS

The chances of recovery without operation in penetrating wounds of the heart must be slight, according to Fischer[8] only 10 per cent. In 1909 Peck[9] collected 160 cases treated surgically, with a recovery rate of 36.87 per cent, and this was probably a fairly accurate index of the chances of recovery at that time. I[10] collected 53 cases reported between 1926 and 1931, with a recovery rate of 73.5 per cent. I was convinced that the recovery rate in the cases more recently reported in the literature was not an accurate index of the chances of recovery because since the number of heart wound cases reported has become quite large only those surgeons having successful ones are likely to make reports. I therefore attempted to gain a more accurate idea of the present mortality rate by sending a questionnaire to the members of the American Association for Thoracic Surgery, the American Surgical Association, and the

Southern Surgical Association. These surgeons were asked to state the number of patients with heart wounds upon whom they had operated, the location of these wounds, and the number of recoveries.* Of the 141 patients operated upon by the members of these associations, 71 recovered and 70 died, a recovery rate of approximately 50 per cent. It seems likely that this more nearly approaches the actual recovery rate than would the figures collected from the literature.

The recovery rate of these 141 patients for the different areas of the heart is given in Table I.

TABLE I

HEART WOUND CASES COLLECTED BY QUESTIONNAIRE

Sent to the Members of the American Association for Thoracic Surgery, the American Surgical Association, and the Southern Surgical Association*

LOCATION OF WOUND	NUMBER OF CASES	RECOVERIES	DEATHS	APPROXIMATE RECOVERY
Left auricle	12	4	8	33%
Right auricle	13	7	6	54%
Left ventricle	52	21	31	44%
Right ventricle	46	29	17	63%
Auriculoventricular septum	1	0	1	0%
Interventricular septum	2	0	2	0%
Coronary arteries	2	2	0	100%
Aorta	3	2	1	66%
Pulmonary artery	5	2	3	40%
Vena cava	1	1	0	100%
Pericardium alone with hemorrhage into cavity	3	3	0	100%
Location not stated	1	0	1	0%
Total	141	71	70	50%

*The author wishes to express his deep appreciation to the members of these three associations for their kindness in answering this questionnaire.

Eleven of the seventeen patients operated upon in the Medical College of Virginia Hospitals recovered and six died. The apparent causes of death in the six fatal cases are as follows.

1. Mrs. R. B. (Case 4.) Extensive destruction of left border of heart by bullet. Cause of death (while patient was on operating table), hemorrhage into left pleural cavity.

2. F. G.[11] Wound through the extreme upper portion of anterior wall of right ventricle and out through the posterolateral wall of pulmonary artery, without injury to the valves. Cause of death (after sixty hours), bilateral pulmonary atelectasis.

3. P. B.[11] Stab wound of lower portion of right ventricle. Cause of death (after nearly six days), clot completely filling cavity of right ventricle and projecting through into base of pulmonary artery.

4. J. W. Wound of pulmonary artery. Patient's condition appeared to be excellent at the time of the completion of the suture of the artery. He died on the operating table while the chest wall incision was being closed. Systolic blood pres-

*Questionnaire sent to 427 surgeons, replies received from 303 surgeons.

sure approximately one minute before death was 135 mm. Hg. The sudden cardiac standstill could not be explained. The wound was reopened, the heart massaged, and adrenalin injected, but without avail. Autopsy showed nothing of significance. Cause of death unknown.

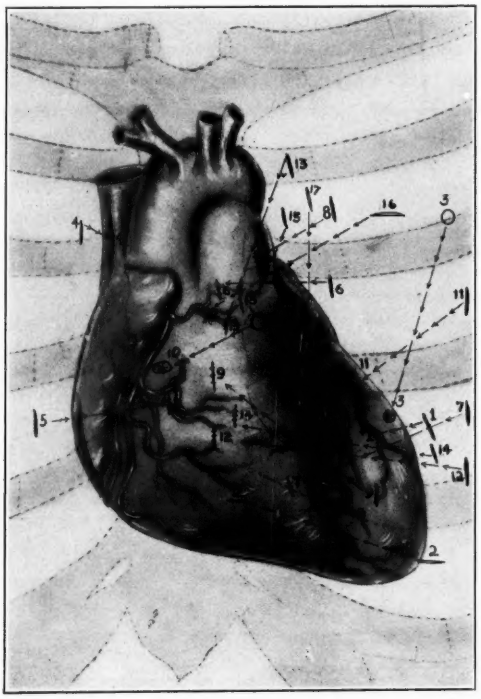


Fig. 2.—Showing the location of the wounds in the skin and the wounds in the heart in the seventeen patients operated upon in the Medical College of Virginia Hospitals. The stab wounds of the heart are indicated by the crosshatched lines. The numbers indicate the chronologic order of the cases.

5. L. J. (Case 3.) Stab wound of upper portion of right ventricle. Cause of death (after forty hours), cardiac failure, probably the result of myocardial disease plus trauma.

6. C. H. Wound of conus arteriosus immediately below pulmonary valves. Death occurred approximately forty hours after operation. The wound was repaired and the patient's condition was entirely satisfactory after his return to the ward, blood pressure 110/60, pulse rate 110. Pulse rate rather promptly dropped to between 80 and 90; and pulse, blood pressure, and temperature remained entirely satisfactory for about thirty-six hours. The patient then developed marked respiratory distress and an extremely rapid pulse rate. Electrocardiograms made a short time before death showed auricular fibrillation and a rapid ventricular rate. Autopsy showed a very early seropurulent pericarditis. The lungs were negative. The heart wound was well approximated, but the anterior pulmonary valve was found to be fixed to the wall of the pulmonary artery by one of the sutures. It seems likely that this was the cause of death, as nothing else of significance was found at autopsy.

In all probability the great additional burden thrown on the heart by the insufficiency of the pulmonary valve, in the absence of hypertrophy, was sufficient to cause acute failure and death.

The acute postoperative complications were as follows:

(a)	Wound infections. Moderately severe	2 cases
	Slight	2 cases
(b)	Atelectasis or pneumonia	3 cases
(c)	Empyema	1 case
(d)	Pericarditis. Fibrinopurulent	1 case
	Fibrinous	1 case
(e)	Blood clot filling right ventricle	1 case
(f)	Postoperative psychosis	3 cases
(g)	Attachment of anterior pulmonary valve to wall of pulmonary artery by suture	1 case

Seven of the eleven survivors were examined after a sufficient time to gain an excellent idea of the final result. The findings at these follow-up examinations are given.

1. W. R.* Penetrating stab wound, left ventricle, with division of left anterior descending coronary artery. Operation Oct. 2, 1930. Follow-up examination, Nov. 10, 1931 (13 months). Heart shadow of normal size and contour. Cardiac function normal.

2. W. J.† Penetrating stab wound of mid-portion of right ventricle. Operation July 4, 1931. Follow-up examination, Jan. 25, 1938 (6½ years). Teleoroentgenogram showed very slight cardiac enlargement, cardiothoracic ratio 50 per cent. Fluoroscopy showed nothing abnormal. Electrocardiograms essentially normal. Heart function normal.

3. H. D.‡ Penetrating stab wound of upper portion of right ventricle. Operation July 26, 1934, performed by Dr. H. J. Warthen. Follow-up examination Jan. 25, 1938 (3½ years). Teleoroentgenogram showed cardiothoracic ratio of 49 per cent. Fluoroscopy showed nothing abnormal. Electrocardiograms essentially normal. Heart function normal.

4. J. B.§ Penetrating stab wound of left ventricle. Operation Aug. 27, 1935. Readmitted July 8, 1937, and died July 18, 1937, nearly 2 years after operation. Entered hospital with peritonsillar abscess, thrombophlebitis of right jugular vein, septicemia. Autopsy showed peritonsillar abscess and thrombophlebitis of right jugular vein. The lungs contained numerous septic infarcts. Spleen weighed 640 gm. No abscesses were demonstrated in the spleen or kidneys. The heart weighed 410 gm. Adhesions practically obliterated the pericardial cavity. The silk sutures were visualized in the left border of the heart, but the scar tissue was very slight in amount. No evidence of wound could be made out on the endocardial side.

5. G. R. Penetrating stab wound of right ventricle with division of small coronary artery. Operation Nov. 29, 1935. Follow-up examination Jan. 21, 1938 (26 months). Teleoroentgenogram showed cardiothoracic ratio of 50 per cent. Fluoroscopy showed moderate fixation of the left diaphragm. Cardiac pulsations were normal. There was no evidence of undue fixation of the heart. Electrocardiograms were essentially normal. Heart function normal.

6. J. L. Penetrating stab wound of mid-portion of right ventricle. Operation Nov. 26, 1936, performed by Dr. H. J. Warthen. Follow-up examination Jan. 12,

*This case was reported as Case 1, Am. J. M. Sc. **184**: 799, 1932, and also as Case 3, Southern M. J. **25**: 785, 1932.

†This case was reported as Case 2 and Case 4, respectively, in the above journals.

‡For full report of this case, see Ann. Surg., **102**: 147, 1935.

§For full report of this case, see Southern M. J. **29**: 18, 1936.

1938 (nearly 14 months). Cardiothoracic ratio of 42 per cent. Cardiac pulsations normal; no fixation. Heart function normal. Electrocardiograms essentially normal.

7. F. E. Penetrating stab wound of the extreme upper portion of the right ventricle or base of the pulmonary artery. Operation March 2, 1937. Follow-up examination Jan. 28, 1938 (10 months). Cardiothoracic ratio of 46 per cent. Slight fixation of left diaphragm. Cardiac pulsations normal. Heart function normal. Electrocardiograms essentially normal.

From these findings and from reports in the literature by Pool[12] and others it seems likely that patients who recover following the repair of a heart wound suffer little or no physical handicap as the result of the injury, even though the pericardium is usually found to be fused with the epicardium.

SUMMARY

The treatment of patients with heart wounds is discussed and a plan is suggested whereby they may be divided into four groups, depending upon whether there is free communication with the pleura or tamponade and also upon the blood loss and upon the severity of the tamponade. Those patients with free communication with the pleura but only slight or moderate hemorrhage are classified in Group I and are treated conservatively. Group II includes those patients with tamponade but in whom there is marked improvement, including a rise in blood pressure to near normal following venoclysis, adrenalin, morphine, etc. They are prepared for operation, but before the operation is begun a cannula is inserted into the pericardium, the pressure obtained, and if possible sufficient blood is removed to decrease the intrapericardial pressure appreciably. The cannula is then left in place for fifteen to thirty minutes, to determine whether or not there will be a rapid recurrence of the tamponade. If it does recur promptly, operation is done; but if the pressure remains low, conservative treatment is continued.

Group III includes those patients with greatly increased intrapericardial pressure who do not show a satisfactory response to conservative measures and who continue to have a low arterial pressure. They should be operated upon without delay; and, if the signs and symptoms of circulatory collapse increase during the period of preparation for operation, aspiration of the pericardium should be done for temporary relief.

Group IV includes those patients with free communication with the pleura and massive intrapleural hemorrhage. They should be operated upon immediately and reinfusion of the blood in the pleural cavity done, while an attempt is made to control the hemorrhage. The number of patients with this type of injury who will survive sufficiently long to secure surgical aid will be small.

It was found through a questionnaire which was sent to the members of the American Association for Thoracic Surgery, the American Surgical Association, and the Southern Surgical Association, that of 141 patients with heart wounds operated upon by the members of these associa-

tions, 71 recovered and 70 died. This is no doubt a more accurate index of the chances of recovery following operation for heart wound than that gained by collecting the cases from the more recent literature.

The apparent causes of death are given for five of our six fatal cases. In one case nothing was found to account for death.

The results of follow-up examinations are given in six of our successful cases and the autopsy findings recorded in one case in which death occurred approximately two years after the cardiorrhaphy from septicemia secondary to a peritonsillar abscess.

REFERENCES

1. Ramsdell, E. G.: Ann. Surg. **99**: 141, 1934.
2. Mayer, Jacob M.: Surg. Gynec. Obst. **62**: 852, 1936.
3. Singleton, A. O.: Am. J. Surg. **20**: 515, 1933.
4. Brunn, Harold: Surg. Gynec. Obst. **55**: 616, 1932.
5. Elkin, D. C.: J. THORACIC SURG. **5**: 590, 1936.
6. Beck, C. S.: Arch. Surg. **13**: 215, 1926.
7. Griswold, R. A.: Kentucky M. J. **34**: 471, 1936.
8. Fischer, Georg: Arch. f. klin. Chir. **9**: 571, 1868.
9. Peck, C. H.: Ann. Surg. **50**: 100, 1909.
10. Bigger, I. A.: Southern M. J. **25**: 785, 1932.
11. Bigger, I. A., and Porter, W. B.: Internat. Clin. I, Series **44**: 133, 1934. (F. G., reported as Case VI; P. B., reported as Case VII.)
12. Pool, Eugene H., and Semsroth, Kurt: Tr. Southern Surg. Assn. **38**: 219, 1925.

DISCUSSION

DR. DANIEL C. ELKIN, ATLANTA, GA.—I believe that the diagnosis of wounds of the heart is relatively easy if the condition is borne in mind in every patient with a penetrating wound of the chest. In 24 operative cases at Emory University, the diagnosis was correct in every instance and the pericardium was not opened unnecessarily. Four patients were treated without operation, and in these the diagnosis was presumably correct and three of them recovered. They were the types referred to by Dr. Bigger in which the tamponade of the heart was not progressive and in whom the venous pressure did not rise. I would emphasize, however, that it is a dangerous procedure to watch a patient who is developing pericardial tamponade since delay may prove fatal.

The diagnosis can be made on the rising venous pressure and the absence or diminution of cardiac movement as seen under the fluoroscope. This latter procedure is of great diagnostic value, but I think it should be done at the bedside in order to avoid moving the patient. I doubt the efficacy of drainage by aspiration, since the pericardium will certainly refill in one or two minutes if bleeding is still active. There may be instances, as pointed out by Dr. Bigger, in which aspiration will do away with the necessity of operation.

I recently saw a patient with a suspected wound of the heart who recovered without operation. Three weeks later he died suddenly and necropsy showed that death resulted from rupture of traumatic aneurysm of a coronary vessel. This death might have been prevented had the patient been treated by operation rather than by conservative measures.

DR. HARRY R. DECKER, PITTSBURGH, PA.—I am sorry that Dr. Bigger did not have the opportunity to go a little more into the technique of the surgery in these cases. In reviewing the literature on this subject and corollary subjects of foreign body injuries, and particularly implantation of the foreign bodies, there is considerable discrepancy in some of the operative details. I should like to ask

Dr. Bigger what he prefers for suture material of these wounds as between, for instance, linen, a nonabsorbable suture material, and catgut, an absorbable suture material; and second, whether or not he drains the pericardium. There seems to be a considerable difference of opinion with reference to that.

Also, I should like to have him discuss his attitude toward foreign body and foreign body implantation in the heart—whether or not he feels that once a foreign body is implanted in the heart it should be removed at an early opportunity, or whether it should be a laissez-faire attitude, depending upon whether or not the patient develops symptoms there.

It seems that the French feel that foreign bodies should be removed at the earliest opportunity rather than letting them migrate or later set up functional disarrangement in the heart.

DR. ALFRED BLALOCK, NASHVILLE, TENN.—I think I am correct in stating that Drs. Bigger and Elkin have operated on more patients with stab wounds of the heart than any other men.

There are two or three points Dr. Bigger made that I should like to reemphasize, if I may. The first of these has to do with the importance of fluoroscoping the patient. The x-ray picture is rarely of any benefit. In one of Dr. Bigger's patients he thought that it was, but the absence of pulsation under the fluoroscope, as pointed out by Dr. Bigger and Dr. Elkin, is perhaps the most important test in making the diagnosis.

Second, Dr. Elkin has referred to the importance of determining the venous pressure. This is done very easily with a needle, with a syringe, with a calibrated tube. Salt solution is allowed to flow in until it stops, and that is the venous pressure.

I should like also to call attention to the fact that the veins at this stage are not very distended. As Dr. Claude Beck and others have pointed out, it takes a while for great distention to take place, so that markedly prominent veins usually are not observed at this time.

I do not recommend this as a test, but an observation which we made on one of our patients is as follows: A healthy, young, strong, colored man came in shortly after receiving a wound in the chest, with a systolic blood pressure of 70. It was the first patient I had ever seen who had had a stab wound of the heart. I was not at all sure what was wrong with him—did not fluoroscope him. We gave him 1,000 c.c. salt solution; his blood pressure was not altered. We gave him 500 c.c. of blood and his pressure did not rise at all.

Dr. Bigger says that he allows these patients to go for a good while in some instances in order to try to decide whether or not there is a wound of the heart. In this he is certainly correct. However, I should like to caution against letting them go too long, because certainly if the human being is at all like the dog, if the pressure remains low due to cardiac tamponade for a period of several hours, there will be capillary congestion all over the body.

Dr. Bigger reported on the fact that there were 52 patients with wounds of the left ventricle. It seems very likely that the person who has not had the experience Dr. Elkin and Dr. Bigger have had may have difficulty, during the excitement, in differentiating between the left and the right ventricles. I have no doubt that some of these wounds which are supposed to be of the left ventricle are probably of the right ventricle.

DR. FRANK BOLAND, ATLANTA, GA.—I am sure the Association notices that southern men predominate in this discussion, because of our large negro population. I rise to make one point in differentiation. We have no members here from Birmingham, but it has been found that Birmingham has a larger number of gunshot wounds of the chest. My explanation of this is that our negroes have a higher aim!

DR. I. A. BIGGER.—I am sorry I did not have time to take up the technique of cardiorrhaphy, but such a discussion will appear in the published paper.

I shall try to clear up the points in question. We use interrupted silk sutures, which I believe have definite advantages. We have not drained the pericardium, but I believe the technique suggested by Beck and Griswold, of making an opening in the pleura for internal drainage, is preferable to external drainage. In our early cases we placed small drains through the chest wall but not into the pericardium.

It would seem to me that the treatment of foreign bodies in the wall of the heart should depend upon whether or not they give rise to symptoms. If they are entirely symptomless, I should be inclined to leave them alone. If they give rise to symptoms, I think removal should be considered.

Dr. Elkin stated that he felt there would be a rapid recurrence of pressure in the pericardium if there was bleeding. I agree with him and think the patient should be on the table prepared for operation, so that there will be no undue delay if the pressure does rapidly recur. If there is no immediate recurrence of increased pressure in the pericardium, conservative treatment should be continued.

I do not advise prolonged waiting in most patients with heart wounds. I think it is better to take them to the operating room and watch them for a short period of time. In only one instance have we watched a patient for more than forty-five minutes to an hour, and this patient was watched three or four hours and then operated upon because of evidence of increasing tamponade.

Dr. Singleton, as you recall, several years ago reported a patient in whom a shot had penetrated the heart wall, resulting in a marked degree of tamponade. Aspiration was done with permanent relief of symptoms.

A TWO-STAGE OPERATION FOR TOTAL PNEUMONECTOMY IN THE TREATMENT OF CARCINOMA OF THE LUNG, DEMONSTRATING A NEW TECHNIQUE FOR CLOSURE OF THE BRONCHUS*

WILLIAM FRANCIS RIENHOFF, JR., M.D.†
BALTIMORE, MD.

THE surgical treatment of malignant tumors in the past has served to emphasize the necessity of removing the entire affected organ with its attendant lymphatics when this is feasible and safe. It is well known that the percentage of ultimate cures is higher among those patients in whom it has been possible to remove the entire organ rather than only a portion of it. In this respect malignant affections of the lungs are no exception to the rule. The lung, fortunately, is one of the few organs in the body which, from an anatomico-physiologic, as well as from a surgical, point of view, lends itself to complete removal together with the accompanying lymphatic glands. Total pneumonectomy is in many respects more easily carried out than partial pneumonectomy and, as a surgical operation, it is a far more logical procedure for dealing with a malignant tumor. The validity of this statement needs no emphasis when one considers the usual anatomic relations of the lungs and of their respective lobes. The presence of a complete fissure separating the lobes has not yet been observed in a study of the thoracic contents in five hundred cadavers, made in the anatomic dissecting rooms and at the time of autopsy. The interlobar fissures have varied from quite shallow ones to those of greater depth, but the presence of lung tissue joining the lobes has invariably been demonstrable. It is possible, therefore, that cells from a malignant tumor situated even in the extreme periphery of a lobe, while migrating toward the hilus in the lymphatic channels, may be forced into similar channels of an adjoining lobe. Furthermore, direct extension of a malignant tumor may occur via the parenchyma, from one lobe to another whenever fusion

*Read before the Twentieth Annual Meeting of the American Association for Thoracic Surgery at Saranac Lake, New York, May 31, June 1, 2, 1937.

†Dr. Rienhoff, of the Department of Surgery, Johns Hopkins University Medical School, for unavoidable reasons was unable to submit this paper for publication until November 16, 1938, although it was presented at the 1937 meeting of the Association. The long delay in receiving it, together with the fact that several important changes have been made in it, seemed to the editor to necessitate the omission of the discussion which was given at the time of the original presentation of the paper.

between adjoining lobes takes place. The hilus of the lung forms a center toward which all lymph and blood channels lead. To leave behind the lymph channels or the glands along the primary bronchus, or a portion of lung tissue, is to invite a recurrence. Unquestionably the majority of so-called lobectomies are in reality only partial pneumonectomies or lobectomies and their inadequacy is at once evident. Moreover, meticulous dissection of the bronchial and mediastinal glands can be accomplished with facility only when an anterior exposure of the lung has been employed. In 85 per cent of the cases in this series the location of the growth, high up in the primary bronchus, precluded the possibility of performing any operation short of a total pneumonectomy. The patients are few in whom the location of the tumor will permit its removal by partial lobectomy, without cutting through or too close to the growth. It is questionable whether true carcinoma of the lung can ever be cured by partial lobectomy. For the foregoing reasons, total pneumonectomy with careful dissection of the lymphatic glands is considered to be the ideal operative procedure for the cure of malignant tumors of the lung.

It is always more satisfactory to the operating surgeon if an operation can be completed in one sitting, but unfortunately in certain patients who are "poor surgical risks," a one-stage pneumonectomy is often not safe. The development of a technique of total pneumonectomy that could be considered safe for the group of patients falling into the category of poor risks would bring within the province of surgical therapy a much greater number of those afflicted with carcinoma of the lung. It might also make it possible to accomplish the extirpation of extensive tumors that would defy removal in one stage.

Because of two deaths as a result of "heart failure" on the right side occurring five and seven days, respectively, following operation, there arose the question of bringing about a more gradual intrathoracic readjustment following total pneumonectomy. It so happened that the two deaths followed removal of the right lung. This observation led to the belief that displacement of the heart to the left was associated with less embarrassment to venous inflow into the right auricle than displacement to the right. Partial occlusion of the inferior and superior cava from the kinking that might accompany lateral displacement, or the twisting or torsion associated with rotation to the right, must interfere with the filling of the heart, aeration of the blood, and efficiency of the peripheral circulation. Further evidence to support this view was obtained from Graham[1] who had operated upon several cases of extreme displacement of the thoracic viscera to the right as a late result of chronic fibroid tuberculosis and upon one case of congenital failure of development of the right lung. In these cases thoracoplasties were performed because of disabling dyspnea and embarrassment of the circula-

tion, in order to allow the trachea and great vessels more nearly to assume their normal positions. Immediate relief from symptoms was obtained. In all these cases the displacement was toward the right side. It would, therefore, seem probable that intrathoracic displacements toward the right are fraught with more danger than those toward the left. The number of cases of congenital absence of the left lung surviving to adult life is greater by far than that of the right lung. It would be entirely too large an operative procedure to combine a total right pneumonectomy and thoracoplasty into one operative session, and it would be confusing and complicated to precede the pneumonectomy with a thoracoplasty.

In view of these observations, a two-stage pneumonectomy has been devised and employed in a series of five cases. Much of the success of this method has been attributed to the fact that the partially-filled, half-collapsed lung that exists following the first stage acts as a cushion, preventing extreme displacement of the mediastinal structures. An additional advantage is the interval of rest which is afforded the patient between stages, affording the opportunity for adjustment to changed circulatory conditions following ligation of the pulmonary artery and the consequent gradual shifting of the mediastinum.

Material and Results.—From June, 1933, when the first pneumonectomy was performed in the Johns Hopkins Hospital, until June, 1937, the entire lung had been removed in each of a series of twenty-three cases. The first eighteen of these total pneumonectomies had been performed in one stage with a mortality of 33 per cent or six deaths. Pathologic examination of the excised lung revealed carcinomas in thirteen cases, benign tumors in two, and tuberculosis in three. Of the carcinomas, five occurred in the right lung and eight in the left. In addition to this series of eighteen patients during the same period, five additional cases of carcinoma of the lung had been subjected to a two-stage operation such as is described in this report, without a death. In this series, the left lung was involved in two and the right in three cases. The ages of these latter five patients varied from 47 to 67 years, and all were afflicted with rather advanced carcinoma of the lung, judging from the duration of the symptoms and the extent of the disease discovered at operation. In each of these cases the lung had been found definitely adherent to the chest wall, and because of age, extent of disease, general physical condition, and the reaction of the patient while on the operating table, they were classified as poor operative risks. Not one of these patients could have lived through a one-stage total pneumonectomy, as judged by the rapid change in their pulse rates, blood pressure, and color following the completion of the first stage.

Yet all survived the two-stage procedure and at this writing, June, 1937, four are alive and perfectly well, one having succumbed one year after operation from metastases.

When the latter series is compared with the first eighteen cases in which the lung was removed in one stage, the results obtained become more striking. The eighteen patients were comparatively young and the growths were discovered at an early stage. The patients ranged in age from 3½ to 46 years. The majority were in the third and fourth decades. In other words, this was an ideal group of patients from the standpoint of operative risk and possibility of cure. Nevertheless, six deaths occurred between the fourth and seventh days postoperatively. There were no deaths from hemorrhage, shock, or opening of a primary bronchus, except as mentioned later in this report, which slight leaks were only temporary and inconsequential. In the early cases, the anesthesia was ether combined with nitrous oxide, and often more ether was administered than should have been. In two patients who succumbed, a great deal of trauma to the pharynx and larynx occurred at the time of insertion of the intratracheal tube and during subsequent moving of the catheter in and out of the trachea. This error in technique was due to inexperience in the use of the intratracheal tube. It is believed that these two deaths could be avoided today. Autopsies revealed that these patients died of fulminating bronchopneumonia in the remaining lung, which may have been the result of the preceding traumatic tracheitis and bronchitis. In the four remaining cases the cause of death was not discovered at autopsy. Three of these were cases of total right pneumonectomy. Cardiac failure due to interference with filling of the right side of the heart subsequent to its displacement was adjudged the cause of death in these three cases. The death in the case of the left pneumonectomy was unexplained.

In this series of twenty-three cases, the mortality for the single-stage pneumonectomy was 33 per cent, for the two-stage procedure it was zero, and the total mortality was 26 per cent.

Preoperative Preparation.—The introduction of air into the pleural cavity in order to bring about a preoperative collapse of the lung is attempted in all cases and accomplished in the great majority. As pointed out in previous reports, the value of this procedure cannot be overestimated.[1] The presence or absence of intrapleural adhesions, as well as fixation of the mediastinum, may be demonstrated in this manner and pertinent modifications in the operative procedure thus anticipated. The technical advantages of removing a collapsed lung rather than an inflated one are obvious and the physiologic benefits of a preoperative disuse of one lung together with the adaptation of the circulatory mechanism to an increased intrathoracic pressure are so fully appreciated as

to make further discussion superfluous. The injection into the pleural cavity of 50 c.c. of beef infusion broth, hydrogen-ion concentration 7.45, containing 1 per cent peptone, has been used routinely in all cases in which it has been possible to bring about a preoperative collapse of the lung. This injection is given forty-eight to seventy-two hours before operation and serves a twofold purpose, namely, protecting the patient against infection, and acting as a stimulus to the formation of granulation tissue, the exudation of plasma, and the obliteration of the dead space which will result from the removal of the lung. Following the injection of the broth there is not only a local, but a constitutional reaction. The temperature, as a rule, becomes elevated, 1° to 2° F., and this is accompanied by an increase in the leucocyte count of the blood to about 15,000. After forty-eight hours the fever subsides, but the increase in the leucocyte count persists. At the same time there is a slight effusion of fluid into the thoracic cavity which contains the broth. This is one manifestation of a fibrinous pleurisy. Repeated daily thoracenteses of small amounts of this fluid, for the purpose of making cell counts, have revealed a very high proportion of young polymorphonuclear leucocytes which reaches its maximum in from forty-eight to seventy-two hours. The average count is 25,000 cells, of which 85 per cent are polymorphonuclear and 15 per cent mononuclear. This ratio changes after seventy-two hours in favor of the mononuclear, both large and small. At the end of one week the latter not infrequently predominate. Associated with this cell-laden effusion the thoracic cavity is almost immediately lined with fibrin which completely covers the exposed pleural surfaces. After twenty-four hours many endothelial sprouts may be seen pushing their way into this scaffolding of fibrinous exudate, and after forty-eight hours the sprouts have developed lumina which are filled with red blood cells; in other words, a lining layer of granulation tissue has been formed. In this manner a preoperative mobilization of the combative and defensive processes of the body against local thoracic and general blood stream invasion has been accomplished. Following operations such as total pneumonectomy for carcinoma of the lung or partial pneumonectomy for suppurative lesions of one lung, there has never been, in our series, a case of generalized empyema or mediastinitis. Following such operations there has always been an accumulation of serosanguineous fluid of varying amounts which partially fills the dead space left immediately following operation. This serous fluid has a pronounced bacteriostatic effect, particularly on members of the pneumococcus and streptococcus groups. As a result of the operative trauma a serous exudate containing erythrocytes is added to the original plasma, which has exuded in response to the stimulation by the injected broth. This accumulation of fluid seems to have a sterilizing or at least an

inhibiting effect upon bacterial growth. Obliteration of the dead space following operation is more rapid in the absence of pus formation: the fibrin is preserved and forms a scaffold for the ingrowth of fibroblasts and endothelium. This finally results in the formation of a multilocular, cystic, fibrous body which occupies the previously empty thoracic space. The bacteriostatic effect of the serosanguineous fluid prevents the accumulation of bacteriolytic and cytolytic products that inhibit new tissue formation, and thus the reparative and constructive processes are accelerated.

Operative Technique and Postoperative Treatment.—As in the one-stage total pneumonectomy, reported for the first time in 1933[2] and again in 1936,[2] so in the two-stage operation, the anterior approach has been found to have many advantages over the lateral or posterior exposures. The incision is made over the third interspace, anteriorly extending from the lateral border of the sternum to the anterior axillary line. The breast, in the case of a female, is then shunted downward by simply dissecting it free from the chest wall. The location of the incision in the male is of no consequence, cosmetically speaking, while in the female at this level it will later be covered by the brassiere. After dividing the pectoral muscles the internal intercostals are incised about midway between the third and fourth ribs, thus avoiding the intercostal vessels and nerves. The pleural cavity is quickly opened by cutting through the parietal pleura for the entire length of the incision and the opening into the chest very much widened by means of a self-retaining retractor or rib spreader. Thus, complete exposure of the hilus of the lung is obtained with minimum operative trauma and with little loss of time. Resection of ribs is unnecessary because anteriorly the ribs are farther apart than elsewhere in the thoracic cage, and they may be disarticulated at the costochondral junctions merely by gently spreading the retractor blades farther apart. When the ribs are reapproximated during closure they are realigned with the costal cartilages and held in position by means of pericostal sutures.

In the first stage of the operation the mediastinal pleura is incised and dissected medialward together with the underlying areolar tissue, thus exposing the pulmonary artery (Fig. 1). The point at which the mediastinal pleura is incised varies, depending on whether the operation is performed on the right or left side. On the right the guiding landmark is the azygos vein, since the right pulmonary artery emerges into the pleural cavity just inferior to this structure (Fig. 2). On the left side the pulmonary artery runs beneath the arch of the aorta (Figs. 3 and 4). The upper or superior surface of the pulmonary artery is immediately exposed and by means of careful blunt dissection, partly with the index finger, the superior and posterior surfaces are freed

from the underlying bronchus (Figs. 2 and 2*a*). The inferior surface is then dissected away from the upper border of the superior pulmonary vein and a No. 10 oiled, braided silk ligature is passed around the mediastinal portion of the vessel at least 2 to 3 cm. proximal to its intrathoracic branches. (Figs. 3 and 4.) Before the first ligature is tightened another is placed about the vessel 0.5 cm. distal to the primary ligature and each is then separately tied in a square knot. The loose ends

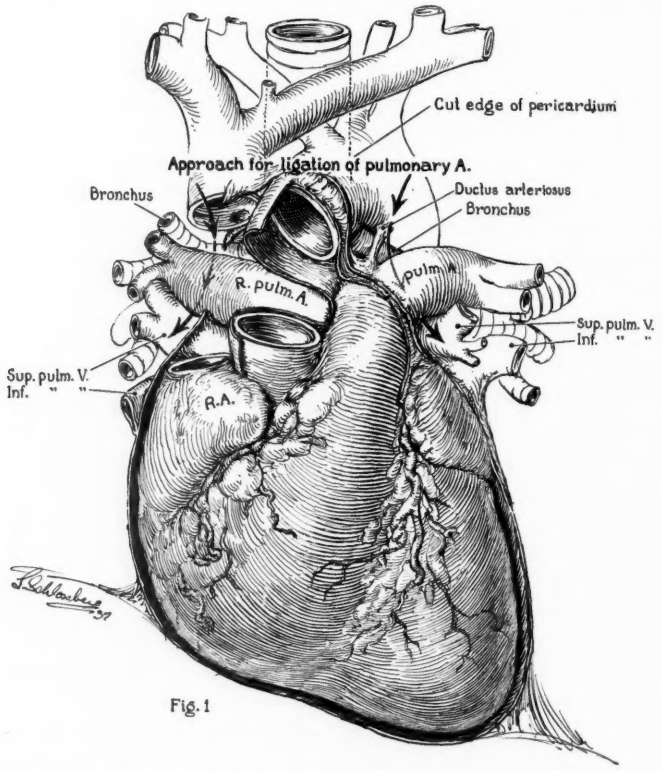


Fig. 1.—Diagrammatic reconstruction demonstrating relations of the pulmonary artery to the pericardial sac. The difference in the length of the right and left pulmonary artery is shown. Reflections of the pericardial sac from the aortic arch and the base of the pulmonary artery are revealed. It should be noted that the pulmonary artery divides its right and left branches, respectively, behind and outside the pericardial sac. The point at which ligation is made both for the one- and two-stage operations is demonstrated by the arrows. The relations of the pulmonary artery to the veins and bronchi are to be noted.

of these ligatures are cut at least 6 cm. long so that they and the obliterated pulmonary artery may be immediately recognized at the second-stage operation. The phrenic nerve is crushed in order to allow a temporary elevation of the diaphragm and obliteration of the thoracic cavity

on that side. The absence of the piston action of the diaphragm resulting from this temporary paralysis aids in maintaining a more perfect collapse of the lung between the first and second stages. It also diminishes the possibility of dissemination of malignant emboli by the expanding lung. The primary bronchus is then stripped of all the bronchial

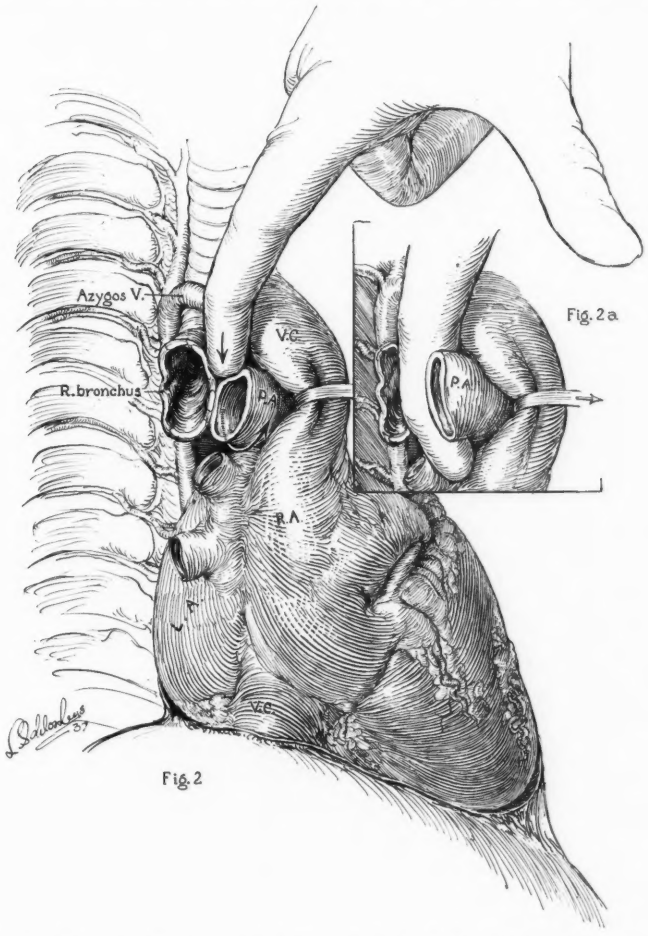
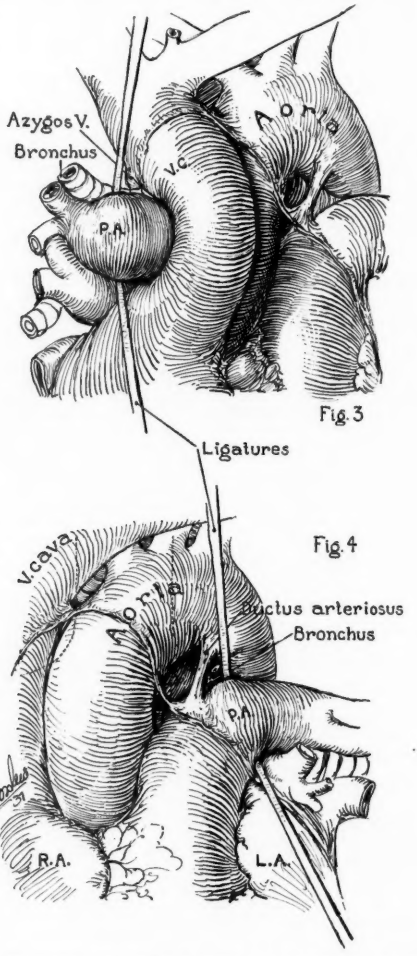


Fig. 2

Fig. 2.—Diagrammatic representation of method of dissecting pulmonary artery from the anterior surface of the primary bronchus. The different angulation of the primary bronchus and pulmonary artery is shown.

lymphatic glands and peribronchial connective tissue, from the bifurcation of the trachea to the point at which the pulmonary artery crosses the bronchus and takes up a position posterior to this structure. The bronchial glands are more easily detected than lymphatic glands else-

where in the body because of their black pigmentation; metastases to them, as a rule, appear as white spots on their surface. Another ligature of braided white silk is placed about the bronchus high up, near the bifurcation of the trachea. This ligature is tied at the first stage,



Figs. 3 and 4.—Untied ligatures are shown around the pulmonary arteries at the level at which these vessels are to be ligated.

because it is placed high up on the primary bronchus near the bifurcation of the trachea above the point at which the bronchial artery applies itself to the posterior bronchial wall. Otherwise, interference with the blood flow through the bronchial artery by ligation of the bronchus further down would, in the presence of ligation of the pulmonary artery,

result in necrosis of the lung. The pulmonary ligament is subsequently divided and ligatures of double silk are loosely placed about the superior and inferior pulmonary veins, but maintenance of the patency of the latter is of the greatest importance and so they are not ligated at the first stage. The bronchial veins are of insufficient size or importance to carry off the blood from the lung supplied by even the bronchial artery, or arteries, alone, and if the flow of blood through the pulmonary veins, either the superior or inferior, is in any way interfered with, moist gangrene of their respective lung drainage beds will ensue, i.e., the superior lobe from blockage of the left superior vein and the inferior lobe from the left inferior vein. The only difference on the right side is that the right middle lobe would seem to be drained more frequently by the right superior pulmonary vein. The advantage of placing these ligatures during the first stage is purely a technical one. In order to isolate the operative field from any reflex nervous effect at the second stage it has been thought advisable to crush the vagus nerve on that side during the primary stage. This may be done at the beginning of the first stage procedure or at the end, but preferably the former. The vagus trunk runs immediately posterior to the primary bronchus and is quite easily accessible. Because of frequent anastomoses with the vagus nerve of the opposite side in the esophageal and gastric plexuses below the point of crushing, and since the departure of the branches to the cardiac plexus and recurrent laryngeal nerve lies above the crushed area, this procedure, which may or may not have value, is considered harmless. It has been found inexpedient during the primary stage to separate adhesions between the parietal pleura and lung, because if a small tear is made in the lung peripheral to an infected portion which is distal to a neoplastic obstruction, a fatal empyema may result. Such adhesions can be separated more safely and with less bleeding later at the second stage. Closure of the wound is then accomplished by drawing the ribs together by means of a rib approximator which holds them in position while perichondral sutures, usually three in number, of No. 10 braided silk are placed and tied. No attempt is made to suture the pleura or intercostal muscles. The pectoral fascia is drawn together with interrupted medium silk sutures, while the skin is closed with fine silk. It is usually necessary in the female to suture the breast subcutaneously, the latter serving as a good tampon over the pectoral fascia. No drainage is employed. A rather snug dressing is applied and the patient returned to the ward. The position in bed, post-operatively, is flat, with the foot of the bed elevated six inches in order that good tracheal drainage may be obtained. The patient is turned slightly upon the operated side so as to have not only the unoperated side free to expand, unhindered during inspiration, but also to further promote

bronchial drainage from the unoperated side. An oxygen tent is used, if indicated, but the intravenous administration of fluids is not employed except in unusual cases of peripheral circulatory collapse, so that strain upon the right side of the heart may be avoided. It is to be noted that the right ventricle is now functioning with only one pulmonary artery as an outlet. Otherwise, the usual postoperative care is observed. Surgical shock has not been observed following the first-stage operation. The short space of time required to complete this procedure, i.e., an average of thirty minutes, may contribute largely to this fact; therefore, intravenous medication is not indicated.

The interval of time elapsing between the first and second stages may roughly be considered to be one week but depends to a great extent upon the reaction of the patient. Each case must be judged individually on its own merits, and definite rules regarding this interval of time between operations cannot be made. Within reason, it would seem better to err by delaying a little longer than not long enough. The final decision on this point must remain for the future.

As a rule, following the first stage there is an initial postoperative elevation of the pulse rate, temperature, and respirations, which requires a period of at least four days for their subsidence to normal. The increase in the respiratory rate is usually accompanied by some slight paroxysms of coughing and expectoration of sputum tinged with blood. In the first cases operated upon in two stages this gave rise to some apprehension, but it was soon discovered to be of no consequence and of very short duration.

The interval of rest between the first and second operations allows the patient to adjust his pulmonary and peripheral circulation to the changed intrathoracic conditions. This consists not only of shunting all blood from the right side of the heart through one remaining lung, but also changing conditions of oxygenation of the blood, as well as the discarding of approximately 50 per cent of the aspiratory action of the thorax. Added to the latter may be the gradual adaptation to some increase in resistance to venous inflow into the right heart following kinking or twisting of the superior and inferior vena cava associated with lateral displacement toward the operated side of the thorax, following removal of the contralateral lung. Thus the question as to the length of the interval between stages is a most debatable point. In a small group of exceptional patients, fortunately, whose heart is apparently functioning perfectly as far as it is possible to determine from electrocardiographic studies before operation, even after a first stage procedure there may be distressing evidence of a peripheral circulatory collapse manifested by profuse perspiration, cold clammy skin, and rapid pulse rate with a diminished pulse volume. These patients

should be transfused daily and also given fluid intravenously. The use of digitalis in these cases would be contraindicated because this forces the heart to work harder against a lowered peripheral resistance. The desired end is to raise the blood volume as well as the blood pressure and in such cases the interval between the operative stages should be prolonged.

At the second stage the thoracic cavity is reopened through the incision made during the first operation. It is only necessary to cut the sutures and separate the lips of the incision by blunt dissection. These wounds have healed per primam in all of our cases so far. The loose ends of the ligature surrounding the pulmonary artery are located immediately, thus revealing the point of ligation of the artery. Following this step the ligatures about the pulmonary veins are tied. The object of the primary encircling ligature of the main bronchus was to occlude the lumen of the bronchus above the suture line at the cut end, and thus remove the pressure and strains resulting from respirations or coughing as well as the collection from gravitation of infected mucus, pus, or detritus in a blind pouch difficult to evacuate and also resting on the inner side of the suture line. After this the amputation of the hilus of the lung is performed from above down on the left and below up on the right. Only the distal portion of the vessels, pulmonary veins, and artery need be clamped. No lung, peribronchial tissue, or lymph glands should be left behind. If such is the case a complete pneumonectomy has not been performed. The primary bronchus is then amputated distal to the encircling ligature of braided silk.

The bronchus, whether it be the right or left, is cut across in the mediastinum not far from the bifurcation of the trachea and the primary encircling ligature. The incision is made slightly oblique to the long axis of the bronchus, on a line running from above and lateral to below and medial. The cut edge of the stump forms an angle of about 45° with the superior border of the primary bronchus and about 135° with its inferior medial border. In addition to the slanting direction of the incision across the bronchus, the cut is made on the bias so that the posterior membranous portion is a trifle longer than the more anterior cartilaginous wall (Fig. 5*a*). Interrupted fine "a" silk sutures are then placed in the membranous portion in such a way that the curved needle (Fig. 5*b*, *c*, *d*) picks up a portion of the posterior membranous tissue a few millimeters proximal to the cut edge. The needle is then inserted into the cut edge of the mucous membrane and the cartilaginous ring of the bronchus directly opposite (Fig. 5*c*). From ten to twelve of these sutures are laid in a fan-shaped pattern. Thus, when the knots are pulled home, the relaxed and relatively tough posterior membranous wall is not only snugly applied or fitted to the inner surface of the semi-

circular cartilaginous ring at all points (Fig. 6*a*) but also, as a result of the way in which the sutures have been placed, the membranous portion is rolled over the cartilaginous cut edge in a way corresponding to the inversion of the intestinal wall. (Fig. 6*a*, *b*, *c*.) The cut ends of the mucous membrane are thus approximated on the inside of the blind-end stump. This method of closure of the cut end tends to flatten out the horseshoe-shaped bronchial cartilage rather than constrict it and, therefore, puts no tension whatever upon the suture line. Two parallel rows of through-and-through mattress sutures are placed proximal to

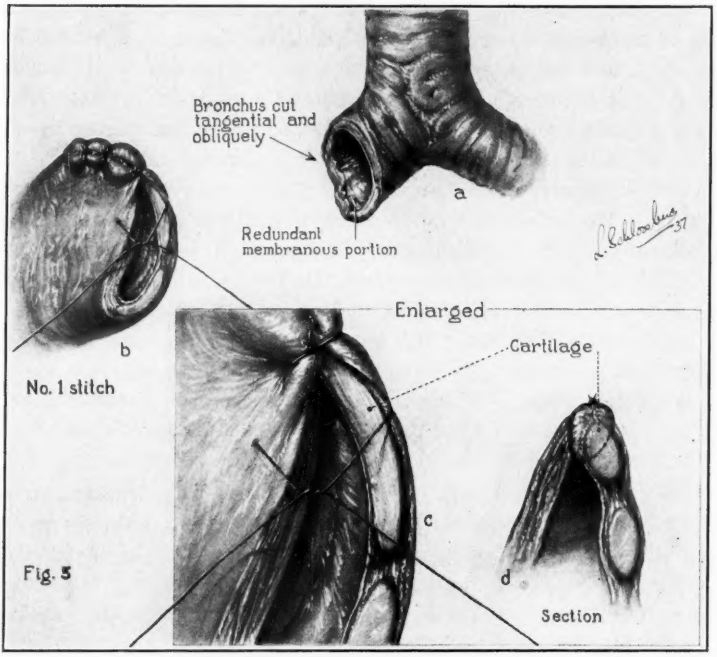


Fig. 5.—The method of closure of the bronchial stump after the preliminary circumferential ligature has been placed around the bronchus and the latter ligated.

the above-mentioned interrupted row. They are separated from the end and from each other by the width of one cartilaginous ring. The suture passes completely through the bronchial walls including the cartilaginous rings. These proximal sutures consist of No. 1 chromic catgut, because the latter would be less likely to cut through the posterior membranous layer than silk. Additional rows of these interrupted mattress sutures may be employed whenever necessary. One row contains about eight sutures. (Fig. 6.)

The posterior membranous portion of the human bronchus is ample to line, as it were, the entire semicircle of the cartilaginous ring. Occa-

sionally on the left side it may be helpful to leave a bit more of the underlip of the membranous portion so as to curl back over the cut end. The membranous wall of the bronchus is abundantly supplied with blood by the bronchial artery.

A fact of some importance may be added. By the use of an oblique incision and a similar technique of closure, an adjacent portion of the trachea may be removed together with the involved bronchus, thus enabling the operator to deal with tumors extending as far as the carina or involving the wall of the trachea along its lateral margins (Fig. 7).

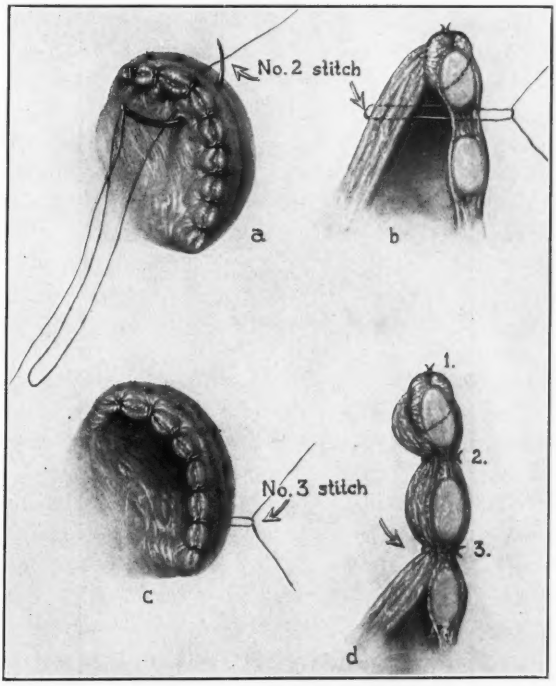


Fig. 6.—Completion of the closure of the bronchial stump, as it appears in situ and in profile.

Following the second stage operative procedure the inside of the thoracic cavity is completely lined with a surface of granulation tissue of considerable thickness. The normal thoracic cavity is markedly reduced because of various encroachments, i.e., the elevation of the diaphragm, the shifting of the mediastinum to the operated side, and the aproximation of the ribs. In all instances, this decidedly shrunken cavity becomes filled with plasma which in the absence of infection will clot, forming a coagulum into which fibrous connective tissue grows

from the surrounding wall of granulation tissue. Between one and two weeks after the second stage operation, this once continuous cavity will have become transformed into a multilocular space comprised of walled-off pockets, the septa or walls of which are formed by the ingrowths of connective tissue. It is inadvisable, therefore, to drain the thoracic cavity after the second operative stage, for if infection occurs it usually manifests itself after the first seven to ten days postoperatively and by

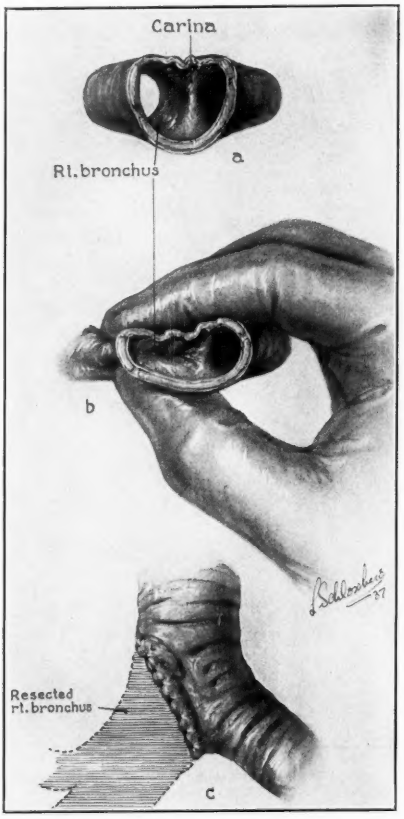


Fig. 7.—Diagrammatic sketch of method of closure of lower portion of trachea for high growths impinging on the latter, demonstrating method of leaving sufficient lumen of the lower end of the trachea to insure free passage of air to the remaining lung.

this time, as a rule, is confined to one small pocket which may then be drained. The closure of the wound after the second stage is therefore similar in all respects to that following the first operation. The patient, following the removal of the lung, is placed within an oxygen tent with the foot of the bed again elevated about six inches. It is also well to

employ the lateral decubitus with the operative side down, as previously stated, in order to secure adequate bronchial and tracheal drainage and at the same time assure the unoperated side free respiratory excursion. This position should be maintained for at least twenty-four hours, when the head of the bed may be somewhat elevated. Intravenous fluids as well as transfusions must be given, if at all, with great caution so as not to overload the heart, but, if surgical shock is present, in sufficient quantities to combat this peripheral circulatory collapse. If any difficulty is to be experienced by these patients, it is usually as a result of infection in a walled-off pocket of the pleural cavity and manifests itself clinically about the tenth to twelfth day. The pulse rate and temperature curves will be elevated above normal for about four or five days postoperatively, following which period there is a return to normal. If infection occurs, it will present the same clinical evidence noted in walled-off infections elsewhere in the body, i.e., general malaise, daily rise of temperature and pulse rate. Not infrequently there may be a simultaneous occurrence of expectoration of a serosanguineous fluid, either clear and later becoming purulent and foul, or being so in the beginning. These low-grade infections have always in our series been thought to be due to anaerobic organisms, probably a contamination from the stump of the amputated bronchus, and perhaps associated with a very small opening in the bronchus. The latter, if present, have all closed after a small tube has been placed within the walled-off cavity and the infected area adequately drained. In the later cases of this series, in which the combined high encircling ligature of the bronchus has been employed together with the above described suture technique for the amputated end, no localized infections have occurred. Follow-up lipiodol bronchograms in a number of the earlier cases have revealed a small walled-off pocket connected with the bronchial stump by a thread-like sinus tract. These pockets probably became lined with bronchial epithelium and remain forever a bulbous dilated pouchlike end of the bronchus.

The remaining postoperative care may be said to be that following any major operative procedure.

DISCUSSION

If the surgical treatment of malignant tumors of the lung is to take its place among the accepted major operative endeavors, the scope of its application must be widened sufficiently to offer a relatively safe procedure to patients of various age groups and in different states of physical fitness.

It has been shown beyond any question of doubt that removal of an entire lung may be accomplished without fear of hemorrhage and with-

out any serious leakage of the bronchial stump. In a relatively young or middle-aged patient in whom an early diagnosis of a malignant growth has been made, it may be feasible to remove the lung in one stage, particularly if the involved lung happens to be on the left side. However, the great majority of patients affected with carcinoma of the lung are in the fifth and sixth decades and in many of them the growth has become so extensive as to be on the borderline of operability. It is to this group of patients that our operation must be adapted. Any attempt to apply an inflexible operative routine in the treatment of patients differing in age, in constitutional symptoms, and in extent of malignant disease will lead to difficulties and disappointments.

CONCLUSIONS

1. Total pneumonectomy would seem to be a better type of operation than partial lobectomy for dealing with carcinoma of the lung.

2. The majority of human lungs are incompletely divided into lobes by fissures of varying depth; thus when lobectomy is referred to, partial pneumonectomy would be the more correct term, for there is nearly always lung tissue joining the lobes in the region of the hilus.

3. In 85 per cent of the cases of this series the tumor was located in, or impinged upon, the hilus so that any operation short of total pneumonectomy would not have removed the new growth.

4. For the cases that constitute what may be defined as poor risks, and for those whose immediate reaction during the early phases of the operation is disturbing to the surgeon, a two-stage total pneumonectomy is recommended.

5. If the patient is apparently in good condition before and during the operation up to the completion of the first stage, i.e., ligation of pulmonary artery, crushing of the phrenic and vagus nerves, division of the pulmonary ligament up to the level of the inferior pulmonary vein, removal of the lymph glands from the primary bronchus, and the ligation of the bronchus near the bifurcation of the trachea, it would seem to be the better policy to perform the total pneumonectomy in one stage. Unquestionably, when feasible and safe a one-stage operation is to be preferred. The purpose of this paper is to outline the method of a two-stage procedure when the necessity for such a procedure presents itself. In the presence of dense adhesions between the parietal and visceral pleura it may be advisable or even necessary to add a third stage to the operation, i.e., that of mobilizing or freeing the lung after the completion of the first stage, the amputation of the hilus being deferred until a later date. Not infrequently the division of dense adhesions is so shocking that further operative procedures are contraindicated for the time.

6. It is probable that intrathoracic readjustments toward the right side are fraught with more danger from displacement and rotation of the heart and great vessels than in the similar shifting to the left side of the thorax.

7. A new technique for closure of the bronchial stump is described.

REFERENCES

1. Graham, Evarts: Personal Communication.
2*a*. Rienhoff, W. F., Jr.: Pneumonectomy: A Preliminary Report, Bull. Johns Hopkins Hosp. **53**: 390, 1933.
b. Rienhoff, W. F., Jr., and Broyles, E. N.: Surgical Treatment of Carcinoma of Bronchi and Lungs, J. A. M. A. **103**: 1121, 1934.
c. Rienhoff: Intrathoracic Anatomical Readjustments Following Complete Ablation of One Lung, J. THORACIC SURG. **6**: 254, 1937.

HEMIDIAPHRAGMATIC PARALYSIS IN THE TREATMENT OF PULMONARY TUBERCULOSIS

JAMES H. FORSEE, M.D.*
ST. LOUIS, MO.

HEMIDIAPHRAGMATIC paralysis is an essential component of modern collapse therapy in chronic pulmonary tuberculosis. Therapeutic paralysis is accomplished by two methods. First, phrenemphraxis, i.e., crushing of a section, 1 cm., of the main branch of the phrenic nerve with division of its accessory branches; second, phrenic exeresis, which is operative evulsion of at least 10 cm. of the nerve. Phrenemphraxis produces a temporary paralysis lasting from a few weeks to several months. Phrenic exeresis produces a permanent paralysis. Simple phrenicotomy so frequently fails to paralyze the hemidiaphragm that the operation now is rarely performed. Over 25,000 operations upon the phrenic nerve in the treatment of pulmonary tuberculosis have been reported in English literature. Phrenic exeresis has been performed on more than 1000 patients at Fitzsimons General Hospital since 1922, the vast majority having been performed since 1929. It is the purpose of this paper to briefly report the present conceptions of the usefulness of hemidiaphragmatic paralysis in the treatment of chronic pulmonary tuberculosis as employed at Fitzsimons General Hospital.

MECHANISMS OF HEALING FOLLOWING HEMIDIAPHRAGMATIC PARALYSIS

The mechanisms of healing in collapse therapy are not well understood.[1, 2] This is particularly true of hemidiaphragmatic paralysis. An explanation of the mechanisms of healing following hemidiaphragmatic paralysis which has been found satisfactory for the clinical application of this procedure includes the factors of relaxation, compression, immobilization, and resultant circulatory changes.

Relaxation, in our present state of knowledge, is probably the single most important factor in the production of beneficial results. Hemidiaphragmatic paralysis reduces the total pulmonary volume from one-sixth to one-third and causes elastic relaxation of the lung. Relaxation aids the shrinking tendency of tuberculous lesions by lessening abnormal tension on diseased areas and minimizes the traumatizing effect of cough and respiratory movements. Distortions from pleural adhesions, including diaphragmatic, are decreased and the elastic tension of the lung due to the negative pressure is reduced.

From the Enlisted Men's Tuberculosis Section, Medical Service, Fitzsimons General Hospital, Denver, Colorado.
*Captain, Medical Corps, U. S. Army.
Received for publication Dec. 14, 1937.

The relaxation produced may initially be greatest in the lower lobe and lesser involved areas, but in the absence of offending adhesions relaxation is shared, after sufficient time for adjustment, by the entire lung and is greatest where shrinking tubercles are greatest. It is, therefore, selective in character.

Greatest controversy exists regarding the compression of a tuberculous lung by hemidiaphragmatic paralysis, and doubtless this factor is of less importance than was formerly considered. The interposition of relatively normal expansile pulmonary tissue above or between the diseased area and the compressing agent (paralyzed hemidiaphragm) has long been considered, by many authorities, sufficient to invalidate compression as an essential factor in the production of beneficial results. The respiratory motion of the lung is activated by the motion of the chest wall and the compression effect of hemidiaphragmatic paralysis tends to be minimized by the compensatory activity of the intercostal muscles. The degree of compression effected depends upon the extent of the diaphragmatic rise and the character of the pulmonary lesions. The elevated hemidiaphragm causes an immediate pulmonary compression somewhat proportionate to the decrease in the longitudinal diameter of the hemithorax, if the positions of the heart and mediastinum are unchanged. Contralateral displacement of these structures proportionately lessens pulmonary compression. The immediate rise is followed by a subsequent rise during succeeding months or years because of pulmonary contraction during the process of healing.

In general, our experience has been similar to that of others who have noted that the best clinical results are obtained in those patients in whom there is an appreciable elevation of the hemidiaphragm.[3, 4] However, marked improvement occasionally occurs without diaphragmatic elevation which cannot be explained on the basis of compression. The tuberculous lung must be capable of collapsing due to its own interstitial changes. A lung containing extensive consolidation, large thick wall excavation, a considerable amount of fibrosis, or excessive rigidity of the bronchial tree would be very resistant to compression by hemidiaphragmatic paralysis. Thus, the prerequisites for compression by hemidiaphragmatic paralysis are diaphragmatic elevation and collapsible pulmonary parenchyma.

Following phrenemphraxis or phrenic exeresis the motor nerve impulses to the hemidiaphragm are interrupted and the organ becomes immobile or moves in a paradoxical manner. Certainly its active rhythmic contractions or pistonlike tug is eliminated, and the diaphragm can no longer regulate, in its normal manner, the difference in the intrathoracic and intra-abdominal pressures during the phases of respiration. Instead, it responds in a passive manner to these pressures in so far as certain pathologic changes in the diaphragm

and pleurae will permit. A functioning hemidiaphragm normally makes approximately 20,000 respiratory excursions in twenty-four hours. A paralyzed and elevated diaphragmatic leaf relieves the diseased lung of much of the effort required to respond to these diaphragmatic excursions. Thus, the effect of immobilization is an important factor in the procurement of pulmonary rest.

The circulatory changes occurring in the tuberculous diseased lung following hemidiaphragmatic paralysis are the subject of extensive experimental, pathologic, and clinical studies. Recent interesting investigations strongly suggest the existence of vasoconstrictor sympathetic fibers within the trunk of the phrenic nerve which innervate the musculature of the bronchi and pulmonary vessels.[2] If this innervation is interrupted, certain changes in the circulation are believed to occur which are of benefit in the healing of tuberculous lesions. Greene has demonstrated experimentally that "upon sectioning the phrenics or after stimulating their central end we have, in many experiments, observed changes in the blood pressure, heart rate, and coronary flow which strongly suggest an intimate reflex relationship between afferent phrenic neurones and the efferent neurones to the heart and coronary vessels."[5] Phrenic interruption probably increases anoxemia by impairing the permeability of the pulmonary alveoli. This favors fibrosis and tends to check the growth of tubercle bacilli. There is experimental evidence indicative of lymph stasis which may decrease toxic absorption and aid fibrosis. Thus the circulatory changes in the lung following hemidiaphragmatic paralysis probably favorably influence healing.

The degree to which the fundamental principles of relaxation, compression, immobilization, and resultant pulmonary circulatory changes are accomplished varies greatly. These factors are not isolated mechanisms which precede or follow one another in an orderly fashion but they are intricate parts of one another. The character and location of the lesions, the contractility and expansile properties of the lung, the mobility of the heart and mediastinum, and the resistance of the bronchial tree, together with the defensive powers of the individual, are important modifying influences, effecting the mechanism of healing.

INDICATIONS

The indications for hemidiaphragmatic paralysis in the treatment of pulmonary tuberculosis cannot be arbitrarily stated. This procedure is a component in our armamentarium of collapse therapy and, as such, should be utilized whenever it will aid in accomplishing cavity closure or the healing of tuberculous lesions. It should seldom be segregated as an independent force to be utilized against a particular pulmonary lesion. A knowledge of its limitations is, of course, of fundamental importance, and results accomplished will depend largely

upon the judgment exercised in its application.[4-6] It is not a replacement procedure for any other form of collapse therapy. For instance, if artificial pneumothorax is the procedure of choice but impossible to accomplish, it can no longer be entertained as indicated, and some other procedure or procedures must be utilized. Often hemidiaphragmatic paralysis is selected. In general, the indications may be classified into three groups: first, as an independent procedure which may or may not be the method of choice; second, in conjunction with other forms of unilateral or bilateral collapse therapy; third, in the treatment of contralateral lung lesions when the opposite lung is undergoing active collapse therapy. Hemidiaphragmatic paralysis may relieve distressing terminal symptoms such as the difficulty in raising sputum. Hemoptysis, if severe or recurrent and pneumothorax is impossible, may be controlled by hemidiaphragmatic paralysis. Persistent hiccough may respond to phrenic paralysis.

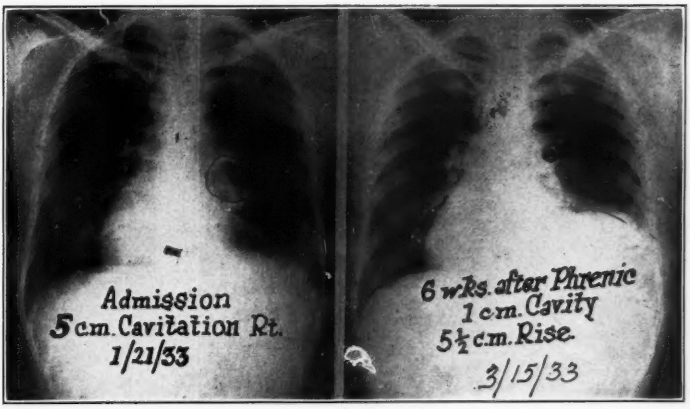


Fig. 1. Fig. 2.

Fig. 1.—Phrenic exercises, choice procedure.
Fig. 2.—Patient well, 1935.

The use of hemidiaphragmatic paralysis as the sole means of collapse therapy may be either as the method of choice or the preferred method in event the choice procedure cannot be utilized. Its use as the method of choice requires keener judgment in the proper selection of patients than any other collapse therapy procedure. There are, however, a few patients for whom it is the method of choice. These patients have recent unilateral lesions limited to the lower lobe or lower portion of the upper lobe, and on fluoroscopic examination wide diaphragmatic excursion is noted. Cavitation may or may not be present (Figs. 1 and 2). We do not believe that phrenic paralysis should be the standard procedure in patients with unilateral lesions, permitting a period of weeks or months of observation to determine

the progress of the disease before attempting artificial pneumothorax.[7] We believe that in the vast majority of cases the latter procedure should be initiated first. Hemidiaphragmatic paralysis has been used as the method of choice in approximately 15 per cent of patients in whom phrenic paralysis has been used on the Enlisted Men's Tuberculosis Section of the Medical Service at Fitzsimons General Hospital from 1929 to 1936, and its use as such has steadily declined.

Hemidiaphragmatic paralysis is indicated as an independent procedure, not as the method of choice, but instead as the method of necessity in a certain group of patients in whom artificial pneumothorax is impossible to accomplish because of complete or partial pleural symphysis. This occurred in 13 per cent of a group of 796 patients originally selected for pneumothorax therapy. The patients initially selected for unilateral pneumothorax therapy had more extensive pulmonary involvement than those in whom hemidiaphragmatic paralysis was used as the procedure of choice (Figs. 3 and 4).

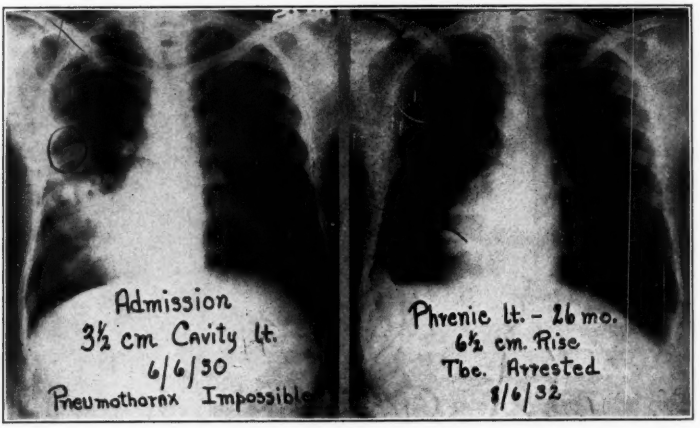


Fig. 3. Fig. 4.

Hemidiaphragmatic paralysis may occasionally be indicated as an independent procedure when choice definitive collapse therapy will be considerably delayed. In instances in which a large number of patients await admission to an institution for definitive treatment, early hemidiaphragmatic paralysis may be desirable. This indication is applicable to persons in the military service stationed at distant foreign posts who must await arrival in the United States before pneumothorax therapy is instituted.[8] In such instances, hemidiaphragmatic paralysis offers the best means of preventing disease progression, and occasionally it has produced sufficient improvement to make further collapse therapy procedures unnecessary.

The greatest field of usefulness of hemidiaphragmatic paralysis is in conjunction with other forms of unilateral or bilateral collapse therapy. It is an important integral part of artificial pneumothorax therapy, and unless adequate reason contraindicates its use, especially when the tuberculous involvement exists in the right lung, the patient undergoing or concluding unilateral pneumothorax therapy should not be denied the benefits of this therapy.[9] Although pulmonary relaxation and compression are already present they are increased, and the factor of diaphragmatic immobility is added.

Pulmonary relaxation and compression may not be satisfactory because of pleural adhesions holding cavities patent. In such instances, undue tension is placed upon areas in the lung which may contain progressive tuberculous lesions. Attempts to increase compression by the administration of larger quantities of air under positive intrapleural pressure may lengthen pleuropulmonary adhesions without complications. However, serious complications may ensue, and satisfactory relaxation and compression are often obtainable by hemidiaphragmatic paralysis without the dangers attending high tension pneumothorax. Positive pressure pneumothorax in the presence of offending adhesions markedly increases pleural effusion, increases the chances of a rupture of lung parenchyma, or may cause active lesions in the pulmonary attachment of the adhesion to ulcerate through the visceral pleura. Post-mortem studies in fatal cases of superimposed spontaneous pneumothorax with patent bronchopleural fistula have frequently demonstrated the opening of the fistulous tract at the site of the pulmonary attachment of the adhesion. The use of phrenic paralysis in conjunction with pneumothorax therapy does not excite such complications, and we have noted that the incidence of intrapleural pneumolysis operations in such pneumothoraces has been materially reduced.

Hemidiaphragmatic paralysis is a useful adjunct to pneumothorax therapy in the closure of basal, central, or hilar cavities. It is probable that paralysis of the hemidiaphragm impairs the tone of the smooth muscle of the bronchi, rendering them more easily collapsible and favoring atelectasis which probably aids cavity closure.

Hemidiaphragmatic paralysis is advantageous in pneumothorax therapy before and after re-expansion of the lung.[9, 10] The elevation of the diaphragm, which becomes more evident as expansion proceeds, reduces the size of the hemithorax and decreases the extent to which the compressed lung must re-expand. Displacement of the heart and mediastinum is minimized, and the functional requirements of the re-expanded lung are decreased because of diaphragmatic immobility. Compensatory hyperactivity of the other respiratory muscles, espe-

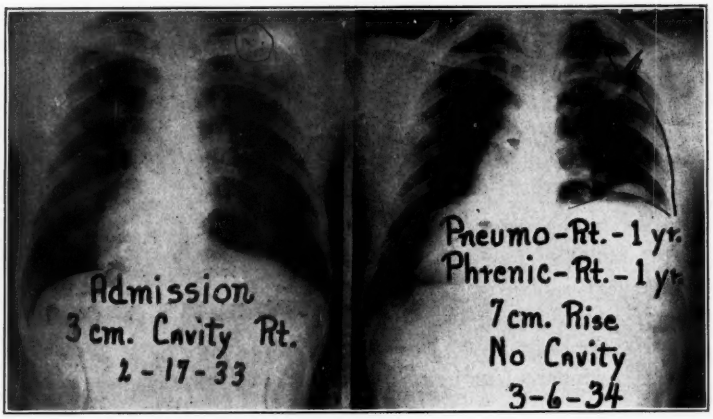


Fig. 5. Fig. 6.

Fig. 6.—Phrenic paralysis supplementary to pneumothorax because pleuropulmonary adhesions held cavity patent.

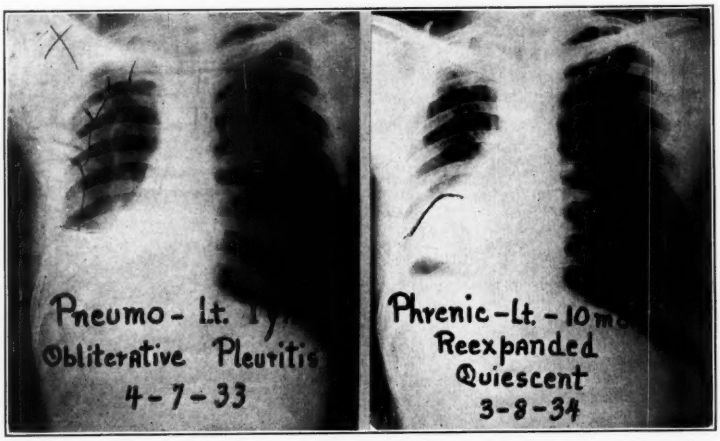


Fig. 7. Fig. 8.

cially if the disease is limited to the upper lobe, does not fully compensate for the pulmonary rest obtained from hemidiaphragmatic paralysis.

In 1935 Pollock and I reported our experience with hemidiaphragmatic in conjunction with artificial pneumothorax therapy and enumerated the following indications for its use[9] (Figs. 5-10):

(1) When pleuropulmonary adhesions cause cavities to remain patent.

(2) When a complicating obliterative pleuritis tends to obliterate the pneumothorax space.

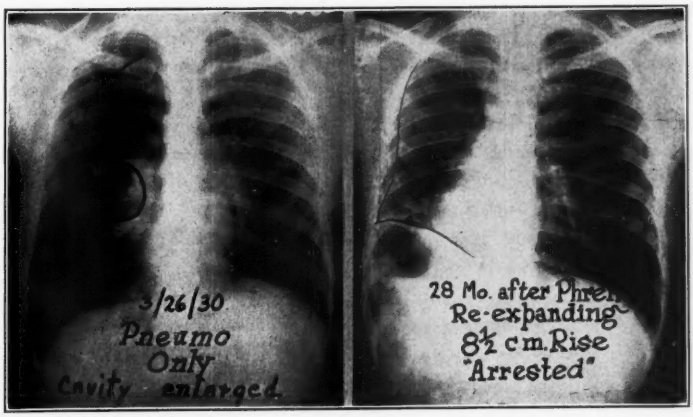


Fig. 9. Fig. 10.

Fig. 9.—Phrenic paralysis indicated as adjunct to pneumothorax to close large central cavity in presence of pleuropulmonary adhesions.

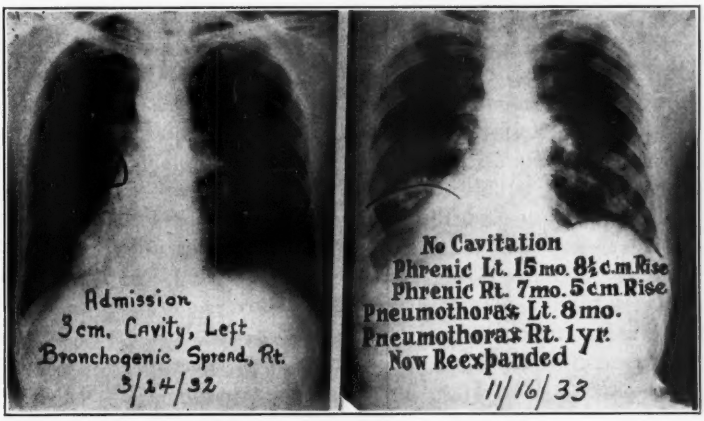


Fig. 11. Fig. 12.

Fig. 12.—Patient well, 1936.

(3) During pulmonary re-expansion after completion of successful pneumothorax therapy.

(4) In pneumothoraces of an unsatisfactory character resulting from partial pleural symphysis.

(5) To close basal, central, or hilar cavities which remain patent though there are no apparent pleural adhesions.

Hemidiaphragmatic paralysis is of very limited usefulness in simultaneous bilateral pneumothorax therapy. It may, however, be of considerable value after one lung has been allowed to partially re-expand, as illustrated in Figs. 11 and 12.

The mere presence of a therapeutically induced pneumothorax is not in itself an indication for hemidiaphragmatic paralysis. The continuance of pneumothorax therapy in the presence of giant excavations which are adherent to the parietal pleura cannot reasonably be expected to result in cavity closure, whether or not hemidiaphragmatic paralysis is added. Similar instances are well known and demand more drastic thoracic surgery. Procedures of collapse therapy must be applied to the individual patient, and no hard and fast rule should be advocated. However, the following of the above indications for hemidiaphragmatic paralysis as an adjunct to pneumothorax therapy have continued to be a most useful guide, and the more closely applied the more pleasing have been our results.

Hemidiaphragmatic paralysis supplementary to extrapleural thoracoplasty has been the source of a considerable diversity of opinion. It was early recommended as a preliminary to thoracoplasty in order to test the ability of the contralateral lung lesions to withstand thoracoplastic collapse. At present it is no longer used as a test procedure but has rather specific indications for its use in conjunction with thoracoplasty. It is indicated in patients with active disease of the lower lobe or, in other instances, in those in whom a complete thoracoplasty, i.e., resection of all ribs, is contemplated. The elevation of the diaphragm as an adjunct to complete thoracoplasty increases compression and decreases pulmonary function. A functionless or immobile hemidiaphragm lessens the possibility of bronchiogenic spread by aspiration and tends to inhibit the development of basal bronchiectasis. It may in certain instances arrest the lower lobe lesions and thereby decrease the number of ribs required to be resected. When performing the upper phase thoracoplasty, as is so often utilized when the lower lobe contains no active lesions, phrenic paralysis is not indicated, as lower lobe compression is not needed while continuance of the function of the lower lobe is much desired.

In cases of active bilateral disease, hemidiaphragmatic paralysis is of great value in treating the contralateral lung lesions while the opposite lung is under active compression therapy. Artificial pneumothorax is often impossible on the worse involved side because of pleural symphysis, and the contralateral lung lesions may preclude thoracoplasty. Patients are being successfully treated by performing hemidiaphragmatic paralysis on the worse involved side to prevent disease progression, and pneumothorax therapy is carried out on the lesser involved side. When the lesions of the better lung are definitely under control, thoracoplasty may be performed contralaterally (Figs. 13 and 14).

In other instances of bilateral disease, pneumothorax therapy may be possible on the more involved side, but the nature of the lesions may be such as to require considerable compression to obliterate

cavities. The collapse required may be too great to permit bilateral pneumothorax therapy, yet contralateral hemidiaphragmatic paralysis may be utilized with safety. Thus, the addition of hemidiaphragmatic paralysis may convert the retrogressive course of tuberculosis into one of gradual improvement and offer the otherwise hopelessly ill individual a chance of recovery.

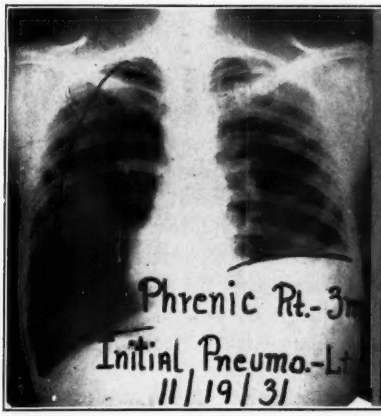


Fig. 13.

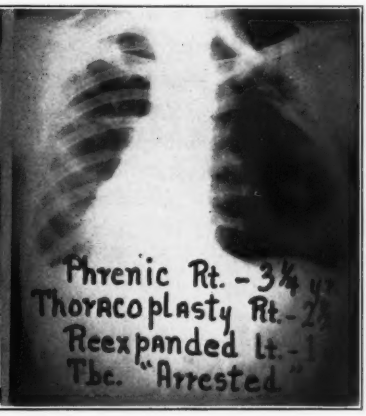


Fig. 14.

Fig. 13.—Artificial pneumothorax; right impossible. (Case reported by W. C. Pollock, Am. Rev. Tuberc. 29: 284, 1934.)
Fig. 14.—Accidental death, 1935. Tuberculosis healed.

The effect of phrenic nerve paralysis upon the hemidiaphragm itself is interesting.[11] It immediately becomes motionless and ascends into the thorax. On fluoroscopic examination the paralyzed hemidiaphragm rises on deep inspiration while the unparalyzed leaf descends. This is called "paradoxical diaphragmatic movement." The entire musculature undergoes atrophy leaving a thin fibrous structure. Histologically, fatty degeneration is present, an occasional atrophic muscle cell may be seen, and the fibrous element is much thinner than normal. Its tensile strength, however, remains good, and the dangers of herniation later are very slight.

As the indications for hemidiaphragmatic paralysis cannot be arbitrarily defined, the results accomplished by its use likewise cannot be precisely stated. A satisfactory result is achieved if hemidiaphragmatic paralysis accomplishes the purpose for which it was recommended. That is, if it was used as the method of choice, did it bring arrest of the disease? If used in conjunction with other unilateral or bilateral collapse therapy did it provide the assistance that could reasonably be expected? O'Brien has stated the problem as follows, "One should not try to weigh the results of one procedure against the others, but rather to look at the picture as a whole, and

evaluate the results of collapse therapy.'[7] Thus, statistical presentations of results are of little value unless accompanied by a summary of the clinical history of the patient, stating the type, location, stage of the disease, and the treatment received. Nehil and Alexander's treatise is excellent.[12] In over one thousand operations performed at Fitzsimons General Hospital increasingly satisfactory results have been obtained through adherence to the indications which have been outlined.

CONCLUSIONS

Hemidiaphragmatic paralysis is an essential component of modern collapse therapy. The present usefulness of this procedure in the treatment of chronic pulmonary tuberculosis is presented. Its greatest value is in conjunction with other forms of unilateral or bilateral collapse therapy. It is an integral part of artificial pneumothorax therapy. The results achieved depend largely upon the judgment exercised in recommending its application, and such results must be adjudged upon the basis of whether or not it met the requirement for which it was recommended. The continued correct use of hemidiaphragmatic paralysis will further the advancement of collapse therapy in pulmonary tuberculosis.

REFERENCES

1. Pinner, Max.: The Mechanism of Healing in Collapse Therapy, Ann. Int. Med. **9**: 501, 1935.
2. Weber, G. W., Jackson, J. J., and Holcomb, F. W.: Phrenicoexeresis, J. THORACIC SURG. **5**: 496, 1936.
3. Matson, Ray W.: Exeresis of the Phrenic Nerve in the Treatment of Pulmonary Tuberculosis, Am. Rev. Tuberc. **22**: 1, 1930.
4. Potter, B. P., Berry, F. B., and Bortone, F.: Phrenic Interruption in the Treatment of Pulmonary Tuberculosis, J. THORACIC SURG. **6**: 424, 1937.
5. Greene, C. W.: Control of the Coronary Blood Flow by Reflexes Arising in Widely Distributed Regions of the Body, Am. J. Physiol. **113**: 399, 1935.
6. Miller, C. M.: Cavity Closure by Combined Pneumothorax and Phrenic Nerve Interruption, J. THORACIC SURG. **5**: 481, 1936.
7. O'Brien, E. J.: The Choice of Procedure in Collapse Therapy, J. THORACIC SURG. **5**: 123, 1935.
8. Pollock, W. C.: Indications for Phrenic Exeresis, Mil. Surg. **73**: 13, 1933.
9. Pollock, W. C., and Forsee, J. H.: Phrenic Exeresis in Conjunction with Artificial Pneumothorax Therapy, J. THORACIC SURG. **4**: 509, 1935.
10. Bendove, R. A., and Davidson, L. R.: Phrenic Exeresis at the Termination of Pneumothorax Therapy, J. THORACIC SURG. **5**: 487, 1936.
11. Stanbury, Stuart W.: Anatomical Changes in the Diaphragm Following Phrenicectomy, Am. Rev. Tuberc. **29**: 528, 1934.
12. Nehil, L. W., and Alexander, John: An Estimate of the Value of Phrenic Nerve Interruption for Phthisis on 654 Cases, J. THORACIC SURG. **2**: 549, 1933.

EFFECT OF PNEUMOTHORAX ON THE RATE OF PLEURAL ABSORPTION OF FLUIDS

An Experimental Study*

Herbert C. Maier, M.D.†
New York, N. Y.

KNOWLEDGE of the effect of pneumothorax on the rate of absorption of fluids from the pleural cavity is important for an understanding of the pathologic physiology of many thoracic diseases. The determination of the influence of therapeutic pneumothorax on the absorption of pleural fluids is also of clinical interest. The problem has been studied experimentally by several investigators but contradictory conclusions have been reported. It therefore seemed worth while to study the subject further by means of direct experimental methods.

In a consideration of the factors which influence the disappearance of fluid from the pleural cavity it should be borne in mind that although there is only a very small amount of fluid in the pleural cavity under normal conditions, the processes of both transudation and absorption are going on simultaneously. The rate of transudation and absorption may be affected by various factors. In instances in which fluid accumulates in the pleural cavity it does not necessarily follow that the rate of absorption of fluid has diminished. The absorption may actually be much more rapid than it was before the condition developed which caused the pleural effusion. In such an instance the increase in the rate of transudation has been greater than the increase in the rate of absorption with the resultant accumulation of fluid in the pleural cavity. Therefore, in a study of pleural absorption it is important not to confuse these two processes, although they are closely linked together.

In many of the pathologic conditions in which pneumothorax or hydrothorax is present the pleural surfaces are far from normal. This will naturally have an important influence on pleural absorption and must be taken into consideration when results of experiments carried out on animals with a normal pleural surface are applied to these disease conditions.

Naegeli[7] studied the effect of pneumothorax on pleural absorption in rabbits. He injected potassium iodide into the pleural space and tested quantitatively for iodine in the urine as an index of the rate of pleural absorption. The pneumothorax was produced by open

*From the Department of Surgery, University of Michigan.
†Aided by the James and Elizabeth Inglis Fund for Thoracic Surgery.
Received for publication Dec. 30, 1937.

operation. As a result of his experiments he concluded that pneumothorax delayed pleural absorption. Since, in the experiment which he cites, in the animal with pneumothorax no iodide appeared in the urine for over three hours after injection of the solution into the pleural space as contrasted with only a forty-five-minute delay in the animal without pneumothorax, it is evident that this delay in excretion must be because of other factors than just the pneumothorax itself, because although pneumothorax might lessen absorption it would not stop it entirely, even for a while. Operative shock and temporary circulatory disturbance might have influenced the results. In view of the many variable factors introduced into the experiment, and the objections to the method and the interpretation of the data, the conclusions drawn are open to question.

In a recent paper Brock[3] came to the conclusion that absorption of fluids from the pleural space is hastened by the additional presence of air. He employed rabbits as the experimental animals and injected a saline solution containing strychnine into the pleural space. A definite amount of the saline-strychnine solution was estimated to contain a lethal dose of strychnine for the rabbit; the death of the animal was considered to indicate the absorption of approximately this amount of fluid. As Brock himself realized, there would naturally be considerable variation in the amount absorbed at the time of the death of the animal, but he felt that the consistency of his results was such as to rule out this factor as invalidating the conclusions. The chief objection to the experimental method employed and one which might easily have influenced the results very profoundly, is that, whereas in his control animals only a small amount of fluid was injected into the pleural space, in the other animals increasing amounts of air were injected in addition to the same amount of fluid. This, in itself, would not be objectionable if the total quantity of the material injected were not sufficient to affect the respiratory rate. As Brock himself showed by experiments on both dogs and rabbits, if the rate and depth of the respirations are increased, the rate of absorption of fluids from the pleural space is greatly increased. Yet in the group of experiments dealing with absorption in the case of a hydropneumothorax no allowance is made for this factor although as high as 75 c.c. of air were added to the 25 c.c. of fluid in the rabbit's pleural space. In dead rabbits of weights similar to those which Brock employed, if both pleural cavities are opened and the lungs allowed to collapse, only between 100 and 150 c.c. of fluid are necessary to fill the thoracic cage completely. So it is obvious that the amounts of air and fluid injected in the above cited experiments would definitely tend to produce respiratory disturbance.

The two papers just discussed are the only ones I have been able to find dealing with the experimental investigation of the effect of pneu-

mothorax on the rate of absorption of solutions from the pleural cavity, and contradictory conclusions are drawn. In view of this it seemed appropriate to investigate the effect of pneumothorax on the pleural absorption of fluid by the use of the most direct method possible.

DISCUSSION OF EXPERIMENTAL METHOD

Type of Fluid.—It has been shown by several investigators that the route of absorption from the pleural cavity varies for different types of fluids. True solutions and solutions which contain particles in the lower range of molecular size are absorbed chiefly by the blood vessels. Particulate matter, on the other hand, is absorbed by the lymphatic system. If one introduces an isotonic solution of a salt, such as sodium chloride, into the pleural cavity, it is absorbed fairly rapidly. Since chlorides are a normal constituent of body fluids, these ions might migrate from the body tissues into the pleural fluid or in the reverse direction. Their migration will be determined by certain physical, chemical, and physiologic forces. Since there is this possibility of simultaneous two-way migration of the chloride ions, it is conceivable that the rate of absorption of the chloride ions from the pleural cavity might be different from that of an ion which is not a normal constituent of the body fluids or is present in only minute amounts. This difference, however, would seem to be purely quantitative, and the effect of some other factor, such as the additional presence of air in the pleural cavity, would tend to be similar in both instances.

It was shown by Starling[3] that the rate of absorption of fluid from the pleural space varies considerably for solutions of different osmotic pressures. If a hypotonic sodium chloride solution is introduced into the pleural cavity there is at first a more rapid absorption of water than of sodium chloride, so that the solution becomes more nearly isotonic. When a hypertonic sodium chloride solution is injected there is a temporary increase in the volume of fluid due to the passage of water from the body tissues into the pleural cavity. Here also the solution rapidly tends to approach isotonicity. It is, therefore, obvious that the amount of solution absorbed will vary considerably if careful attention is not paid to the type of solution used. This is particularly true if the duration of an experiment is only a few hours or less.

Type of Experimental Animal.—Whereas in man there is no free interchange of air or fluid between the two pleural cavities, this is not true in some animals which are frequently used in experimental work. In the dog the two pleural cavities in one area are separated only by a very thin mediastinal septum which is readily permeable to air and fluid. Because the mediastinum of the rabbit is more like that of man than is the case with either the cat or dog, most investigators have preferred to use the rabbit in experimental work where this anatomic difference might be a factor in the experimental results. However, in preliminary experimentation with rabbits difficulties were soon encountered and certain uncontrollable variables observed; these variable factors were of sufficient degree probably to have marked influence on the results obtained. A discussion of these is indicated because of their possible influence on the results obtained by Brock. These factors are the following:

1. When relatively small amounts of fluid or air had been injected into one pleural cavity of the rabbit (the right side was used because it has the larger capacity), there was an increase in the rate and depth of respiration. This increased respiratory movement was shown by Brock and Blair[4] and confirmed by additional experiments (see below) to increase the rate of absorption of fluids from the pleural cavity. Furthermore, when quantities similar to those which Brock

employed in some of his experiments were injected, definite evidence of respiratory distress was observed even though animals of similar size were employed.

2. As increasing quantities of air are injected into the pleural cavity, there is a fairly rapid change in the intrapleural pressure toward the positive side. Because the rabbit becomes dyspneic and the depth of respiration increases, there is a wide fluctuation between the intrapleural pressure at the height of inspiration and at the height of expiration. After the intrapleural pressure has been elevated to a certain degree there may be a sudden drop due to rupture of the mediastinal septum. The exact effect which these fluctuations in intrapleural pressure might have on the rate of absorption of fluids from the pleural cavity has not as yet been determined.

3. Because of the relatively small size of the rabbit's thoracic cage, one can work only with small amounts of fluids and, therefore, inaccuracies in recovery of the remaining fluid introduce a considerable error. This can be easily shown by injecting a known amount of fluid into the pleural cavity of a dead rabbit, opening the chest, and measuring the amount which can be recovered.

EXPERIMENTAL DATA

Dogs were used as the experimental animal. Since the mediastinum of the dog is readily permeable to air and fluid, both pleural cavities of the dog were considered in the experimental observations as if they were a single unit. In order to keep factors as nearly constant as possible, equal quantities of fluid, or air and fluid, were injected into each pleural cavity, but only measurements of the total from both sides were considered to be of significance. As the size of the dogs used varied considerably, this factor had to be taken into consideration. Although it was realized that the chest capacity would not vary directly with the weight, yet by injecting a given quantity of fluid, or air and fluid, for each kilogram of body weight, gross variations in this factor could be eliminated. Furthermore, in each instance a dog in whose pleural cavity only fluid was injected was compared with one of similar weight in whom fluid was injected in the presence of pneumothorax. Weights were estimated only to the nearest kilogram so that in each set of experiments the same amount of fluid was injected into two dogs, one of whom had no air in the pleural cavity while the other had a pneumothorax.

In the first three groups of experiments the dogs were under morphine and urethane anesthesia; this anesthesia lasted throughout the duration of the experiment. This had the great advantage of assuring quiet respirations throughout the experiment, thereby eliminating changes in respiration as completely as possible. In those dogs in which both air and fluid were injected, the pneumothorax was instituted immediately before the introduction of the fluid. Intrapleural pressure readings were taken before the introduction of either air or fluid, and at intervals throughout the experiment. At the end of a two-hour interval following the injection of the fluid into the pleural cavity, the dog was quickly killed with chloroform. During the entire experiment the dog was lying flat on its back so as to lessen the puddling of fluid on one side due to position. Immediately after the death of the animal, the parietal pleura was exposed, but not incised, at the uppermost part of the chest in order to see if the lung was well expanded in the cases in which no air had been introduced; this was done in order to eliminate the possibility of having inadvertently caused a pneumothorax by injury to the lung with the needle in those cases in which only fluid was introduced. Both pleural cavities were then opened widely and the fluid which remained was withdrawn and measured. In the early experiments, in order to determine what percentage error might be introduced by incomplete removal of fluid, the pleural cavity was washed with distilled water after the original residual fluid had been removed. This wash fluid was then quantitatively analyzed for the substance originally introduced. The error due to this factor of incomplete recovery of residual injected fluid was found

to be less than one per cent and to be approximately constant and in the same direction in all experiments; it has, therefore, not been taken into consideration in the various calculations.

A solution of sodium chloride was injected into the pleural cavity in the various experiments. The exact concentration of the saline solution was determined in each case. In addition, in order to study the absorption from the pleural cavity of a substance which is not a normal constituent of body fluids, some experiments were carried out in which phenolsulphonephthalein in saline was introduced into the pleural cavity.

The volume of fluid recovered at the end of the two-hour period was determined in each case. The chloride content of the remaining fluid was determined by the Volhard method, and the percentage of chloride absorbed in two hours was determined.

RESULTS OF EXPERIMENTS

GROUP 1.—In this group of experiments an approximately physiologic sodium chloride solution was used. In one series of dogs, 10 c.c. of saline per kilogram of body weight were injected into each pleural cavity. In another series of animals of similar weights to the group without pneumothorax 20 c.c. of air per kilogram were injected into each pleural cavity before the introduction of the 10 c.c. of saline per kilogram. The results are given in Tables I and II.

TABLE I

ABSORPTION OF FLUID*

WEIGHT OF DOG (IN KG.)	TOTAL AMOUNT OF SALINE INTRODUCED INTO THORAX (IN C.C.)	PERCENTAGE OF FLUID ABSORBED IN 2 HOURS IN DOG WITHOUT PNEUMOTHORAX	PERCENTAGE OF FLUID ABSORBED IN 2 HOURS IN DOG WITH PNEUMOTHORAX	PERCENTAGE LESS ABSORPTION IN DOG WITH PNEUMOTHORAX
10	200	18	9	50
10	200	23	12	48
13	260	16	11	31
14	280	21	15	29
15	300	19	10	47
16	320	17	13	24

*With 0.89 per cent sodium chloride solution.

TABLE II

ABSORPTION OF CHLORIDE*

WEIGHT OF DOG (IN KG.)	TOTAL AMOUNT OF SALINE INTRODUCED INTO THORAX (IN C.C.)	PERCENTAGE OF CHLORIDE ABSORBED IN 2 HOURS IN DOG WITHOUT PNEUMOTHORAX	PERCENTAGE OF CHLORIDE ABSORBED IN 2 HOURS IN DOG WITH PNEUMOTHORAX	PERCENTAGE LESS ABSORPTION IN DOG WITH PNEUMOTHORAX
10	200	26	11	58
10	200	33	16	52
13	260	23	16	30
14	280	31	20	35
15	300	25	18	28
16	320	23	16	30

*With 0.89 per cent sodium chloride solution.

It will be noted that in every instance the dog with pneumothorax absorbed less fluid and less chloride than the dog of the same weight without pneumothorax. There is naturally considerable variation between the quantities absorbed in the

individual experiments. There is not a single instance, however, even without consideration of the weight of the dogs, in which as much fluid or chloride was absorbed with pneumothorax as without pneumothorax.

GROUP 2.—In this group of experiments a similar procedure was carried out with the exception that a 0.77 per cent sodium chloride solution was used. The results in this group are given in Tables III and IV.

It will be noted that the results are similar to those obtained with the sodium chloride of somewhat greater concentration; again the animals with pneumothorax absorbed less fluid and chloride. A greater percentage of the fluid was absorbed in these experiments, however, than in the group of experiments cited in Tables I and II because of the difference in the tonicity of the sodium chloride solution.

TABLE III

ABSORPTION OF FLUID*

WEIGHT OF DOG (IN KG.)	TOTAL AMOUNT OF SALINE INTRODUCED INTO THORAX (IN C.C.)	PERCENTAGE OF FLUID ABSORBED IN 2 HOURS IN DOG WITHOUT PNEUMOTHORAX	PERCENTAGE OF FLUID ABSORBED IN 2 HOURS IN DOG WITH PNEUMOTHORAX	PERCENTAGE LESS ABSORPTION IN DOG WITH PNEUMOTHORAX
8	160	29	23	21
9	180	31	18	42
10	200	30	25	17
11	220	27	22	19
13	260	29	17	41
15	300	28	17	39

*With 0.77 per cent sodium chloride solution.

TABLE IV

ABSORPTION OF CHLORIDE*

WEIGHT OF DOG (IN KG.)	TOTAL AMOUNT OF SALINE INTRODUCED INTO THORAX (IN C.C.)	PERCENTAGE OF CHLORIDE ABSORBED IN 2 HOURS IN DOG WITHOUT PNEUMOTHORAX	PERCENTAGE OF CHLORIDE ABSORBED IN 2 HOURS IN DOG WITH PNEUMOTHORAX	PERCENTAGE LESS ABSORPTION IN DOG WITH PNEUMOTHORAX
8	160	38	21	45
9	180	32	22	31
10	200	29	21	28
11	220	30	19	37
13	260	30	14	53
15	300	30	13	57

*With 0.77 per cent sodium chloride solution.

GROUP 3.—The purpose of this group of observations was to determine to what degree pneumothorax influenced the rate of absorption of dyes from the pleural space. A dye was used as an example of a substance which is not present ordinarily in the body fluids. It was desired to ascertain whether the absorption of this type of substance was effected in the same manner by the presence of pneumothorax as was saline solution. The experiments were conducted in the same way as those in the preceding groups.

In ten dogs a solution containing 0.25 c.c. of phenolsulphonephthalein in each 100 c.c. of isotonic saline was injected. The amounts of solution and air injected were the same per kilogram of body weight as in the previous experiments. Dogs of approximately the same weight were used in the group without pneumothorax

as in the group with pneumothorax. The estimates of the amount of the dye absorbed were determined colorimetrically. The results were as follows: percentage of phenolsulphonephthalein absorbed in two hours by five dogs without pneumothorax, 41 per cent, and five dogs with pneumothorax, 26 per cent.

These experiments show that absorption of this dye is slower when pneumothorax is also present. Both the amount of fluid present at the end of the experiment and the concentration of the dye in the remaining fluid were greater in the presence of pneumothorax. The effect of pneumothorax is similar here to the effect noted with the absorption of sodium chloride solution.

GROUP 4.—The object of this group of experiments was to determine the effect of deep breathing on the rate of pleural absorption. As has been previously stated, Brock and Blair[4] performed experiments which indicated that an increase in the rate and depth of respiration increased the rate of pleural absorption. As the results of the experiments were in accord with those reported by Brock, only a small number of determinations was made.

Each dog in this group of experiments weighed approximately 11 kg. Ten c.c. of a 0.89 per cent sodium chloride solution per kilogram of body weight were injected into each pleural cavity. Ether anesthesia without morphine was used so that respirations would not be depressed. Deep breathing was induced by stimulation with carbon dioxide. None of the animals had pneumothorax. Otherwise, the experiments were conducted in the same manner as in the previous groups. The results of the experiments are given in Table V.

These experiments confirm the observation of Brock and Blair that an increase in rate and depth of respiratory movements causes more rapid pleural absorption. It is to be noted that the deep and rapid respirations caused a relatively more rapid disappearance of the chloride than of the fluid.

TABLE V

ABSORPTION OF FLUID AND CHLORIDE IN RELATION TO RESPIRATORY RATE IN DOGS WITHOUT PNEUMOTHORAX

DOG	TYPE OF RESPIRATION	PERCENTAGE OF FLUID ABSORBED IN 2 HOURS	PERCENTAGE OF CHLORIDE ABSORBED IN 2 HOURS
Dog 1	Quiet breathing; average respiratory rate 20 per minute.	26	26
Dog 2	Slight increase in rate and depth of respiration; average respiratory rate 30 per minute.	27	29
Dog 3	Marked increase in rate and depth of respiration; average respiratory rate 70 per minute.	33	46
Dog 4	Same as Dog 3.	31	51

GROUP 5.—The purpose of this group of experiments was to determine the relative effect of deep breathing on pleural absorption in animals with pneumothorax as contrasted with those without pneumothorax.

Each dog in this group weighed approximately 11 kg. Ten c.c. of a 0.89 per cent solution of sodium chloride per kilogram of body weight were injected into each pleural cavity of each dog. In the dogs with pneumothorax 20 c.c. of air per kilogram of weight were injected into each pleural cavity in addition to the fluid. Deep breathing was produced by inhalation of carbon dioxide, and the

respiratory rate was kept as constant as possible in all experiments. Animals were under ether anesthesia throughout the duration of the experiment. The results are given in Tables VI and VII.

TABLE VI

PERCENTAGE OF FLUID ABSORBED IN TWO HOURS WITH DEEP AND RAPID BREATHING (4 DOGS)

Average Respiratory Rate, 70 Per Minute

WITHOUT PNEUMOTHORAX	WITH PNEUMOTHORAX
31%	25%
33%	29%

TABLE VII

PERCENTAGE OF CHLORIDE ABSORBED IN TWO HOURS WITH DEEP AND RAPID BREATHING (4 DOGS)

Average Respiratory Rate, 70 Per Minute

WITHOUT PNEUMOTHORAX	WITH PNEUMOTHORAX
51%	35%
46%	38%

These experiments indicate that if the respiratory rate is approximately the same in each of two animals the dog with the pneumothorax will absorb pleural fluid more slowly than the one without pneumothorax. On the other hand, when the rate of pleural absorption in dogs breathing quietly and without pneumothorax (Tables I and II) is compared with that in dogs breathing rapidly and deeply with pneumothorax (Tables VI and VII), it is seen that the rate of absorption is more rapid in the latter cases. In other words, rapid, deep respirations may more than offset the tendency of the pneumothorax to slow the rate of absorption. This is further supported by the following observation. In one dog in which it was intended to study the rate of absorption during deep breathing without pneumothorax the lung was inadvertently injured, and extensive collapse of both lungs resulted. This dog's respiratory rate varied between 80 and 110 per minute throughout a two-hour period. This dog absorbed 36 per cent of the fluid and 52 per cent of the injected chloride. At the time of death this animal had a positive intrapleural pressure. Attempts were made to repeat this experiment but were unsuccessful because circulatory failure developed in these other animals.

As was mentioned above, where the method of performance of the experiments was described, intrapleural pressure readings were taken at the beginning of each experiment, at intervals during the experiment, and just before the animal was killed. In all instances except the one in which the lung was injured, the pleural pressures remained negative. The average intrapleural pressures at the beginning of the experiments were minus 8, minus 6. After the injection of the fluid, or the air and fluid, the pressures averaged minus 5, minus 3. Whereas it is possible that the intrapleural pressure might influence the rate of pleural absorption, it is unlikely that the slight changes which occurred in these experiments could have a significant effect. In experimentation with normal animals without pleural adhesions it is not possible to alter the intrapleural pressure to any great extent without producing other disturbances such as dyspnea, which would confuse the picture. This makes the evaluation of the effect of variations in intrapleural pressure on the rate of pleural absorption of fluids difficult. It is possible that the rapid rate of absorption in the dyspneic animal is partly due to a more positive intrapleural pressure during part of the respiratory cycle in these instances, but there is no evidence at present to support this.

DISCUSSION

The results of the experiments show a very definite diminution of the rate of absorption of a given amount of saline solution from the pleural cavity when air is also present in the pleural space. An analysis of the effect which pneumothorax has on the avenues of absorption from the pleural cavity would lead one to expect this result. Pneumothorax causes a slowing of the lymph flow through the thoracic duct.[5] It has been shown that there is delay in the removal of particulate matter, such as India ink, from the pleural space when pneumothorax is present.[2] Particulate matter is removed from the pleural cavity by the lymphatic system. Also, when air as well as fluid is present in the pleural space, there is a greater degree of collapse of the lung, and as a result the amount of blood flowing through the lung during quiet breathing is diminished.[6] Associated with this reduction of blood flow through the partly collapsed lung, there is a diminution in the cardiac output.[1] This, if it has any appreciable effect, will tend to diminish the blood flow through the vessels in the parietal subpleural and mediastinal areas through which the absorption from the parietal portion of the pleura occurs. In addition, when both air and fluid are present, the fluid will tend to be in contact with a smaller surface area of both parietal and visceral pleurae because the air will be in contact with a considerable portion. Of course, the parietal and visceral pleura in the part of the pleural space where the air has collected will be moist and probably slight absorption may occur there because of the movement of fluid.

As it has been shown that pneumothorax delays the absorption of crystalloids and dyes, and as other investigators have shown that pneumothorax delays the absorption of particulate matter, it seems logical to assume that the rate of absorption of proteins would also be reduced by pneumothorax. There would be quantitative differences, however, in the effect of pneumothorax on the rate of absorption of these different substances just as there are with various concentrations of sodium chloride solution.

Caution must be exercised in the application of the above-described experiments to clinical pleural effusions. Here one has two factors, both absorption and transudation, to consider. In the formative stage of a pleural effusion the effect of pneumothorax on the rate of transudation will be the important factor. This has not as yet been determined. In the resorptive stage of a pleural effusion, in view of the experimental results reported above, it would seem that the introduction of air would retard the disappearance of the pleural effusion.

The results of the experiments reported in this paper indicate that unless careful attention is paid to the depth of the respiratory movements, this factor may introduce a considerable error when observa-

tions of the effects of other phenomena on the rate of pleural absorption are made. This would seem to be the explanation for the results obtained by Brock, which are contradictory to the ones herewith reported. Another factor, however, which must be considered is the intrapleural pressure. As Brock was working with rabbits in which the mediastinum is not readily permeable as in the dog, more positive pressures could have been developed by the injected air and fluid than in the case of the dog. Unfortunately, the effect of changes of intrapleural pressure on the rate of absorption of pleural fluids is not clearly understood.

CONCLUSIONS

The rate of absorption of fluid from the normal pleural cavity during quiet breathing is diminished by the additional presence of air in the pleural space.

Increased respiratory motion causes a more rapid absorption of fluid from the pleural cavity.

In cases of hydropneumothorax with considerable dyspnea the increased respiratory motion may more than offset the tendency of the presence of the air to diminish the rate of absorption of the pleural fluid.

REFERENCES

1. Andrus, W. DeW., and Wilson, J. D.: The Effects of Closed Pneumothorax and Phrenicotomy on the Cardiorespiratory Function, Arch. Surg. **19:** 1205, 1929.
2. Bettman, R.: Reaction of Pleura to Particulate Matter, Especially in the Presence of Pneumothorax, Arch. Surg. **10:** 523, 1925.
3. Brock, R. C.: Observations on Pleural Absorption, Brit. J. Surg. **21:** 650, 1934.
4. Brock, R. C., and Blair, E. A.: The Importance of the Respiratory Movements in the Formation and Absorption of Pleural Fluids, J. THORACIC SURG. **1:** 50, 1931.
5. Dolley, F. S., and Wiese, E. R.: Effects of a Large Closed Bilateral Pneumothorax on Thoracic Lymph Flow, Arch. Surg. **18:** 542, 1929.
6. Moore, R. L., and Cochran, H. W.: The Effects of Closed Pneumothorax, Partial Occlusion of One Primary Bronchus, Phrenicectomy, and the Respiration of Nitrogen by One Lung on Pulmonary Expansion and the Minute Volume of Blood Flowing Through the Lungs, J. THORACIC SURG. **2:** 468, 1933.
7. Naegeli, T.: Über die Resorption von Flussigkeiten aus der Pleurahöhle, Ztschr. f. d. ges. Exper. Med. **1:** 164, 1913.
8. Starling, E. H., and Leathes, J. B.: On the Absorption of Salt Solutions From the Pleural Cavity, J. Physiol. **18:** 106, 1895.

ANESTHESIA FOR INTRATHORACIC OPERATIONS

H. H. Bradshaw, M.D.*
Philadelphia, Pa.

THE revived interest which thoracic surgery is enjoying at present is dependent on several factors, one of which is anesthesia. Knowledge of pulmonary physiology and pathology has been accumulating for centuries, since the time of Vesalius. Knowledge and experience in the surgery of intrathoracic diseases are of very recent origin. Thoracic surgeons today are working in the light of the trials, errors, and successes of their predecessors. Some of us have either not been familiar with, or have ignored, the work and observations of the men who have preceded us. This is especially true of anesthesia in open chest operations because it is possible now occasionally to observe a patient on the operating table, deeply cyanotic, struggling for air, with the lung herniating through the operative wound, and with the trachea partially filled with secretions and blood.

The two most important requirements of the anesthesia in thoracic surgery are the prevention of anoxemia and the removal of foreign material from the trachea and bronchi. The drug that is used to produce anesthesia is of very secondary importance compared to the other requirements, and the one that allows a given operator to meet them best is the one that he should use. There undoubtedly is a great variation of opinions on the drug that should be used. The prevention of anoxemia and the aspiration of foreign material can be accomplished by means of intratracheal tubes.

Vesalius in his "De Corporis Humane Fabrica Libre Septum" published in 1555 described an open chest preparation which he was accustomed to make in animals for the purpose of demonstrating to students different kinds of pulses. Parts of his experiments are very illuminating and are presented not only because of their historical interest but also because of the fundamental physiologic knowledge conveyed by them. The following excerpts are from a translation made by Dr. Cecil Drinker of the Harvard Medical School.

"On either side of the thorax I make a cut down to the ribs in the lines of the costochondral junctures, and then another transverse incision so that I may to some extent free the bones from the overlying muscles. I now cut away the intercostal muscles from the periosteum in two interspaces and with the hands alone avulse the ribs from the periosteal envelopes. The cleared ribs are now broken from their

Received for publication Jan. 14, 1938.
*From the Jefferson Medical College Hospital.

cartilages and bent aside, thus exposing a great stretch of costal pleura, which, being transparent, displays the motion of the lungs. This membrane being broken, one may see the lung fall away from the side wall, the motion of the chest remaining unchanged.

"In order that everything may be clearer, I now break many of the ribs from their cartilages, making the broadest possible opening. Both parts of the lung, which in the injured chest move beautifully with the thorax, are seen through the thoracic membranes. As these membranes are progressively torn away, the lungs are seen as a result of perforation to fall together and collapse. And now on the other side I free the ribs from the costal cartilages with a sharp knife, and from the cartilages I dissect off the diaphragm that I may be able to turn up toward the neck the sternum and the attached tissues. This maneuver brings the heart into view inside the pericardium, and when this is opened one may observe how much water it contains and how the heart beats. You will not be able to observe the cardiac motion for long since suffocation of the animal will come on account of the collapse of the lungs.

"In order to restore the life of the animal, an opening is made in the upper part of the trachea into which a pipe made from a reed is introduced. And when it is blown into, as the lung rises up, the animal receives air. The lung should be inflated to the degree to which it occupied the thorax in life. The heart now gathers new strength and its motion will change beautifully. Therefore, by maintaining repeated inflation of the lungs you may have opportunity to examine the motion of the heart both by touch and by sight as much as you desire. When the lung is allowed to be flat for a time, the motion of the heart and pulse is observed to become wavelike, creepy, and vermicular. On reinflation of the lungs it becomes large and quick and may exhibit extraordinary inequalities."

Here was the key to successful anesthesia in intrathoracic operations. But these important observations of Vesalius were lost sight of or at any rate were not applied to human beings to any extent until the present century. Many pharyngeal and tracheal tubes were devised in the interim but mainly for the relief of laryngeal obstruction in diphtheria and for the treatment of asphyxia of the new born. The use of such tubes for the inflation of lungs and introduction of the anesthetic is recent.

Kuhn[1] in the first decade of this century used endotracheal tubes for anesthesia with to-and-fro breathing and added a small catheter for the aspiration of foreign material from the trachea. This is essentially the method that we have employed. The work of Sauerbruch and Miculicz at Breslau in 1904 on the negative pressure chamber deserves great credit for renewing interest in the physiologic aspects of thoracic surgery.[2] Samuel Robinson in this country was outstand-

ing in his experimental observations on differential pressures in open chest surgery. In 1906[3] he published the results of animal experiments in which he had verified the investigations of Volhard and Sollmann and added further observations to them. In 1910[4] he devised a positive pressure cabinet for thoracic surgery at the Massachusetts General Hospital. It presented certain features which he regarded as improvements over some of the earlier types of cabinets. One year previous to this time he had described a smaller portable apparatus for emergency and "out-of-town" operating. Previous to this in 1908 he referred to the administration of oxygen through the trachea to the bronchial bifurcation. He found that deep intratracheal administration of oxygen would maintain the normal pulse rate and respiratory movements in spite of removal of the front of both chests in the presence of almost complete collapse of the lungs. If air was substituted for oxygen under the same conditions, he found that it was necessary to keep the lungs at almost full inflation. The difficulty in passing a tube to the bifurcation of the trachea in a human presented the main objection to this type of anesthesia. This was in the early days of the bronchoscope and can be readily understood. He believed that this method would never substitute the mask or cabinet method either in humans or in animals. However, writing in 1912 on the possibilities of pneumectomy, he asked whether fatalities previous to 1904 were due to operative pneumothorax, the effects of which at the time were not overcome by the use of differential pressure.[5] He stated that anesthesia administered through an intratracheal tube is the most ideal in all thoracic surgery. The patient never becomes cyanotic regardless of procedure or degree of lung destruction. Volhard and Sollmann,[6] Meltzer and Auer,[7] and Elsberg,[8] all deserve great credit for working out some of the mechanical and physiologic details of intratracheal insufflation.

Various modifications in apparatus for anesthesia in open chest surgery are continually being introduced. They almost always add some complicating factor to an otherwise simple procedure. Closed endobronchial anesthesia is advocated by some. The bronchus to the healthy lung is completely occluded by a cuff-tipped catheter, thus enabling complete isolation of the lung undergoing operation from respiration. This arrangement prevents any foreign material from reaching the sound lung during the actual operation. No vent for the escape of gas is provided except through the intratracheal tube. If sudden pressure is exerted as a result of connecting a tank of gas or oxygen in the presence of an open reducing valve, rupture of alveoli may result. Of course such neglect on the part of the anesthetist should never occur but such accidents do happen. The mercury has been blown out of a manometer because of such neglect. At the end of the operation, when the cuff-tipped catheter is removed,

material which is present in the trachea can easily find its way into the sound lung. Secretions and blood are squeezed out of the diseased lung during the operative manipulation and extend alongside the catheter into the trachea. It is difficult to introduce another tube for aspiration beside the endobronchial catheter. To obviate this, we have preferred to use large intratracheal tubes, preferably of the Flagg type, so that frequent aspiration from near the operative site can be employed throughout the operation.

Some surgeons are using spinal anesthesia for pulmonary lobectomy and with apparently good results. Probably the main reason for resorting to spinal anesthesia is to preserve the patient's cough reflex. However, when large vessels and other structures at the lung root must be dealt with surgically, it seems advisable to have the cough reflex somewhat depressed and the operative field as free from motion as possible. If adhesions do not prevent excessive motion of the lung and mediastinum, the surgeon can grasp the lung and lessen these motions. Oxygen can be given by means of a gas mask and machine. But it is obvious that such an arrangement does not allow for complete control of lung inflation, the giving of oxygen, and the removal of foreign material from the respiratory system. It is true that by means of the mask and tank pressure the lung can be maintained in an inflated condition, but rather high pressures are required if any degree of obstruction is present because of the presence of foreign material in the trachea or bronchi. If high pressures are maintained for any length of time, the stomach may easily become distended. Many of the earlier thoracic operations were done with only a mask for maintaining lung inflation, but the disadvantages were so great that it was practically abandoned. It is impossible to gain complete control of the situation with only a mask. Certainly if everything goes well a mask is satisfactory, but if there is laryngeal spasm from light anesthesia or from strong afferent stimuli, as from surgical manipulation about the lung root, or if the bronchi become filled with secretions or blood, the method becomes almost useless.

Before starting any anesthetic on patients with bronchiectasis it is advisable to have a laryngoscope, intratracheal tube, and adequate suction available. We prefer to give a basal dose of avertin, averaging 80 mg. per kilogram, depending upon the physical status of the patient followed by nitrous oxide-oxygen and ether by inhalation. Frequent coughing and some cyanosis is often seen during the induction phase. As soon as the patient is adequately relaxed the intratracheal tube is introduced under direct vision through the laryngoscope. The head of the table is lowered and a thorough aspiration is done of all the secretions present. This usually has to be repeated several times before fairly complete emptying of bronchiectatic cavities is obtained. These manipulations require considerable time, often

forty-five minutes or more. But time does not seem such an important factor if the patient is given an abundant supply of oxygen. And this can be accomplished only if all foreign material is removed from the bronchial system. The intratracheal tube is brought out through a perforated rubber diaphragm in the top of an ordinary anesthesia facepiece and the tube connected to the anesthesia machine.

The anesthesia is maintained throughout the operation by an oxygen-rich, ether atmosphere. The anesthetic passes through the intratracheal tube into the lungs, some of the anesthetic escapes around the tube into the pharynx. The patient inspires and expires both through and around the tube. The pressures maintained in the system and in the patient's lungs are best determined by the surgeon. If a little more or a little less inflation of the lungs is required, this can easily be accomplished by means of adding oxygen from the tank or by opening an exhale valve. Manometers are not essential because the surgeon always has the lung under direct vision; before the chest is opened and after it is closed, no pressure is required. It is essential to have a nearly airtight system from the anesthetic machine to the patient's lungs, or else difficulty will arise in maintaining adequate inflation of the lungs because of leakage. Some of the anesthetic and oxygen will be lost from the surface of the lung when the chest is opened, so that it may be necessary to keep a constantly greater flow than is used in the usual abdominal or closed chest operation.

As the operation proceeds and the diseased lung is manipulated more and more, secretions are squeezed out into the bronchus. This is evident to the anesthetist by cyanosis, difficulty in maintaining inflation, and by the sound of material moving to and fro in the intratracheal tube. The gas machine is disconnected from the tube for a few seconds and a catheter introduced through the tube, and the foreign material is aspirated. This interruption in the flow of the anesthetic and oxygen does not upset the patient to any extent provided that adequate oxygen has been given prior to the interruption and the flow is not discontinued too long. Time is ample for complete aspiration without disturbance to either the patient or surgeon. During this interval, if excessive mediastinal movement does occur, the surgeon grasps the lung and makes slight traction and thereby diminishes the motion. Surgical manipulation about the lung root often causes coughing, especially if the anesthetic is light, or it may cause an apnea. To obviate this we have recommended the injection of novocain about the pulmonary plexuses. Cocaine has also been suggested for this purpose but we have had no personal experience with its use in this connection. Novocain seems to work quite satisfactorily. As the tourniquet is released from the lobe hilus in doing a lobectomy, it is advisable to introduce the suction tube and determine whether or not there is any bleeding into the bronchus. In the event of any

noticeable hemorrhage the tourniquet can be reapplied, the bronchus more adequately closed, and the vessel ligated. Hemorrhage at this stage of the operation may readily fill up the sound lung and lead to asphyxia. Except for aspiration, the system need not be disturbed throughout the operation because some of the expired air passes through soda lime, and the carbon dioxide is removed and some of it is lost from the lung surface into room air. Excess breathing from accumulated carbon dioxide has never been observed in these patients.

At the end of the operation the lung is partially inflated as the chest is closed. Caution should be used in the reinflation of atelectatic lobes. If it is carried out rapidly, pulmonary edema of the lobe results. This occurred in one of our patients. A true mediastinal goiter which had caused atelectasis of the middle lobe was removed. Before the chest was closed it was thought wise to reinflate the lobe, and as the lobe expanded it became quite boggy, waterlogged, and heavy. This caused no obvious difficulty in the patient. But it is probably more physiologic to allow the lung to re-expand over a period of days rather than over a period of minutes. The trachea and bronchi are thoroughly aspirated before the tube is removed. After removing the tube, oxygen is given by mask until the patient is placed in an oxygen tent.

Intratracheal anesthesia in infants and small children presents some mechanical difficulties that are not met with in adults. A tube that is adequate for suction and for introducing the anesthetic and oxygen practically fills the trachea in these patients. There is very little space available between the trachea and the tube for the escape of gas. Unless great care is used it is very easy to overdistend the lung.

This accident occurred in an 18-month-old girl who was being operated upon for a large intrathoracic neurofibroma. The intratracheal tube was introduced and was connected with the gas machine. Subcutaneous emphysema of the neck was noticed and the tube was removed. In addition to the emphysema a small right pneumothorax was produced. It is possible that the bronchial wall may have been weakened from pressure by the tumor but it seems more likely that too great pressure was introduced into the trachea in the absence of an adequate escape vent. This child was operated upon at a later date, but a water valve, preventing too high pressures from occurring, was introduced into the system, and no difficulty was encountered. This can, of course, be prevented by the careful introduction of gas, by using a two-phase apparatus with pressure and suction, or by intermitting the positive phase and providing a water valve for the escape of gas.

This discussion has been concerned mainly with pulmonary lobectomy for bronchiectasis because this type of operation is being done more frequently than any other intrathoracic operation and because

the large amount of purulent material in bronchiectatic cavities renders the anesthetic more difficult. The same conditions, however, often are present in an obstructing carcinoma with distal bronchiectatic cavities or if there is necrosis in the tumor. For mediastinal tumors and other tumors in the absence of bronchial obstruction a simpler type of intratracheal anesthesia may be used. In these patients the need for aspirating is not often encountered. A curved, soft rubber tube of the Magill type may be introduced through the nose into the trachea. Adequate inflation and oxygenization can be maintained by means of a mask and the anesthetic machine. In heart surgery both pleural cavities may be opened but no difficulty is observed with such an anesthetic setup.

The mechanical and physiologic requirements of anesthesia in open chest surgery can be adequately and easily met. The simplest apparatus that will accomplish the task is the apparatus that should command respect and be more generally used. The old cry to "stop at the pleura" need be heard no longer if the fundamental observations of Vesalius are kept in mind.

REFERENCES

1. Kuhn, F.: Pulmonale Narkose. Therap. Monatsch., Berl. **17**: 447, 1903.
2. Sauerbruch, F.: Ueber die Ausschaltung der schadlichen Wirkung des Pneumothorax bei intrathorakalen Operationen. Zentralb. f. Chir. Leipz. **31**: 146, 1904.
3. Robinson, Samuel: Experimental Surgery of the Lungs. 1. Thirty Animal Operations Under Positive Pressure. Annals of Surg. **47**: 184 Feb. 1906.
4. Robinson, Samuel: A Positive Pressure Cabinet for Thoracic Surgery, Surg., Gynec., & Obst. **10**: 287, 1910.
5. Robinson, Samuel: Pneumectomy: Its Possibilities. Annals of Surgery **55**: 513, April, 1912.
6. Volhard, F.: Ueber künstliche Atmung durch Ventilation der Trachea und eine einfache Vorrichtung zur rhythmischen künstlichen Atmung. München. Med. Wchnschr. **55**: 209, 1908.
7. Meltzer, S. J., and Auer, J.: Eine Vergleichung der "Volhardschen Methods der künstlichen Respiration ohne respiratorische Bewegungen venuendeten Methode." Zentralbl. f. Physiol. Leipz. u. Wien. **33**: 442, 1909.
8. Lilienthal, H., and Elsberg, C. A.: Erfahrungen am Menschen mit der Methode der intratracheale Insufflation. (Meltzer) Berl. klin. Wchnschr. **47**: 958, 1910.

PRACTICAL POINTS IN LOBECTOMY

IRVING A. SAROT, M.D.*
NEW YORK, N. Y.

DURING a year spent at the Brompton Hospital the opportunity was afforded the writer of observing the operations and the pre- and postoperative courses of a large series of lobectomies; the case records of a much larger series were also available. This paper is based on the observations made on these cases and records.

As experience with the operation of one-stage lobectomy has increased, certain aspects of the preparation and postoperative care of these cases and of the procedure of the operation itself have necessarily undergone revision. The essential principles are still the same, however, as stated in the paper by Roberts and Nelson.[1] It is with the frequently troublesome details that are not often stressed in writings on the subject that this paper is concerned.

PREOPERATIVE STUDY AND PREPARATION

In the preoperative study of a case of bronchiectasis the bronchography with radiopaque iodized oil is the most important single step. The entire bronchial tree of each side should be studied separately, anteroposterior and lateral films being taken, and the exact extent of the disease determined.[2, 3, 4] Care must be taken to fill the middle lobe bronchi, especially on the left. In several cases, after the lower lobe had been removed, persistence of cough and sputum was noted, and bronchography revealed the presence of bronchiectasis in the middle lobe. If this bronchiectasis had been noted preoperatively, the middle lobe (or on the left side, its analogue) might have been resected at the same time. A further point which is now being investigated is whether apparently normal middle lobe bronchi can become bronchiectatic, or whether pre-existing mild bronchiectasis may become aggravated when the remaining lung is called upon to expand and fill the hemithorax after lobectomy.

The consideration of the degree of emphysema, if present, is very important. It is an old axiom that patients with marked pulmonary emphysema and diminished vital capacity have a lowered reserve

*Formerly Chief Clinical Assistant to Mr. J. E. H. Roberts, in Thoracic Surgery at Brompton Hospital, London.

Dr. Sarot submitted the manuscript of this article to Mr. Roberts who expressed approval of it as a description of his technique in lobectomy at the Brompton Hospital. Dr. Sarot was on a fellowship in surgery from the Mount Sinai Hospital, New York City.

Received for publication Dec. 20, 1937.

with which to withstand acute respiratory emergencies such as are liable to occur postoperatively. This becomes doubly important in chest surgery, in general, and especially in procedures of pulmonary ablation. A patient with a "barrel" chest, fixation of the ribs in the position of full inspiration, practically no costal motion, and a diminished vital capacity, represents the extremely poor risk.

The amount of costal motion during respiration may be noticeably increased by careful training in breathing exercises conducted by a competent masseuse. These exercises have been fully described by MacMahon.[5] Patients with poor costal motion are benefited by these exercises, often to quite a marked degree, with actual increase in the vital capacity and diminution in dyspnea on exertion. In mild cases this training is a valuable preoperative measure. As a matter of routine, all patients are taught these exercises before operation, and they are resumed as soon as possible after operation. It is believed that such treatment aids in expanding the lung and restoring chest wall function.

Bronchoscopy is now performed on these patients only if bronchography has shown evidences of bronchial obstruction, and not as a means of drainage. In cases with a large amount of sputum, prolonged postural drainage is prescribed and has given excellent results in diminishing the amount of sputum and evidence of toxicity, thus facilitating the operation and the prevention of postoperative complications. In performing this postural drainage the positions used are those described by the late Mr. H. P. Nelson,[6] based on the bronchial anatomy (Fig. 1). In all lesions in front of the tracheal axis the drainage is best when the patient lies on his back; if the lesion is posterior, then the patient should lie prone. If the lesion is in the line of the tracheal axis, he should lie on his side, with the affected side uppermost. When the lesion is in the upper zone the sitting position facilitates drainage; if in the middle zone, he should lie flat. For lower zone lesions, the feet should be raised or if a Nelson bed[6] is used, the pelvis should be high and the head low.

The very frequent association of chronic paranasal sinus disease and of chronic tonsillar infection with bronchiectasis has led to the routine examination of each case by the rhinolaryngologist and the administration of appropriate treatment before the lobectomy. It is felt that such a procedure is a valuable aid in the prevention of postoperative complications in the remaining lung.

The question as to whether an artificial pneumothorax should be induced has given rise to discussion. It is no longer believed that sudden opening of the pleura causes shock and that an artificial pneumothorax prevents it. But the separation of the pleural layers by a small air space does facilitate the actual operative entry into the

pleural space. In many cases the emptying of the bronchi in the diseased lobe is facilitated by an artificial pneumothorax, especially if the lower lobe remains adherent to the diaphragm. However, a large pneumothorax also succeeds in collapsing the healthy parts of the lung and may make subsequent re-expansion more difficult. While an artificial pneumothorax is induced routinely before operation (except in cases of lung abscess), it is kept small. About two days before operation an initial instillation of about 300 c.c. of air is performed, and the next day a refill of the same size is given. An x-ray film is then taken as a guide to the degree of collapse obtained and the amount of adhesions present.

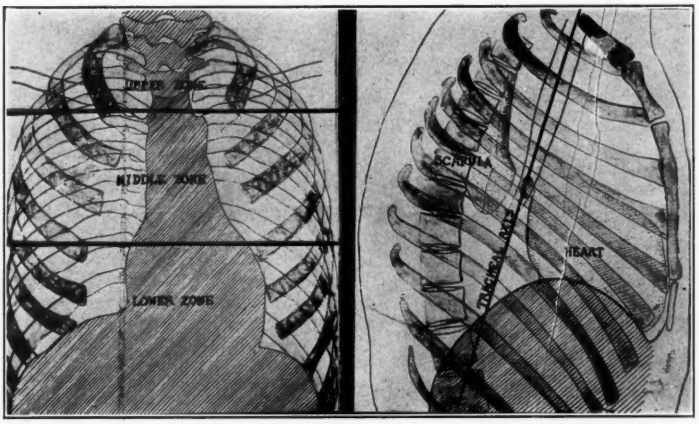


Fig. 1.—Showing the anteroposterior and lateral views of the normal chest. (After H. P. Nelson, reproduced by courtesy of British Medical Journal, August 11, 1934.)

A phrenicectomy used to be done before each lobectomy. With increased experience, the diaphragmatic motion has been found to interfere less during dissection. Consequently phrenicectomy is no longer done before lobectomy. The presence of an actively moving diaphragm is considered desirable for the complete re-expansion of the remaining lung.

ANESTHESIA

The ideal anesthetic or combination of anesthetic agents is still being sought. Because diathermy is used in hemostasis and in resecting the left middle lobe analogue, a noninflammable mixture is usually preferred. Nitrous oxide, oxygen and chloroform, with a minimum of rebreathing (or passed through a carbon dioxide absorption chamber) in order to minimize lung movement, has been used almost routinely and has proved very satisfactory. Positive pressure is unnecessary, and spinal anesthesia has been used successfully.[7] Intratracheal administration is not absolutely necessary but has proved desirable, since

at the same time intermittent intratracheal suction through a catheter can be applied. This is believed to aid in preventing infection of the opposite lung by secretions from the infected lobe.

OPERATIVE PROCEDURE

The operative procedure has become well standardized. The usual intercostal incision in the seventh space for a lower lobe excision, and the fourth space for an upper lobe, with only rib division posteriorly and without resection, leaves on closure a complete and undeformed chest wall.

The dissection of pleural adhesions is much facilitated if an assistant uses a small light on a long malleable stem to transilluminate the adhesions as the surgeon cuts them, thus enabling him easily to avoid cutting lung or diaphragm. In extremely adherent cases the dissection has in part been performed extrapleurally without obvious ill effect.

The pulmonary ligament usually contains at least one fair-sized blood vessel which must be ligated. In one case in which there was no bleeding when the pulmonary ligament was cut no ligature was applied, and postoperative hemorrhage necessitated reopening of the chest and ligation of the vessel.

The lobe should be amputated between two tourniquets whenever possible to avoid mass infection of the pleura by pus from the infected bronchi. An extremely important step in this part of the operation is the complete sealing off of the pleural cavity by large packings. When the patient is a child the lobe should be amputated at a slightly greater distance from the tourniquet, since the pedicle tissues retract to a greater degree than in an adult, and subsequent suture of the stump may prove difficult. It seems to make very little difference in the occurrence of postoperative bronchial fistula or secondary hemorrhage whether the pedicle is secured by two continuous all-inclusive sutures or by numerous radially placed mattress sutures. Both methods are alike in avoiding dissection of the pedicle and individual ligation of the vessels and bronchi, thus avoiding the opening of tissue planes which might lead to mediastinitis.

Where more than one lobe has been affected the lower and middle lobes have been removed, both on the right and the left sides. Occasionally on the right side and always on the left side there is no fissure dividing middle from upper lobe, and it is necessary to cut across the pulmonary tissue with the diathermy. Because each lobe has an independent blood supply and as the line of incision follows a potential fissure, there is little bleeding. Wherever possible it is preferred not to suture the cut surface of the lung but to leave it open and thus facilitate drainage of the infected surfaces.

Damage to the pericardium must be carefully avoided. It may occur through inclusion of the pericardium in the bite of a hemostat or in the tourniquet applied to the lobe. During a difficult dissection the pericardium may be incised, in which case it should be carefully sutured at once. It may be significant that in one of the patients with foulest and most profuse sputum, in whom the pericardium was opened during dissection and closed at once by suture and carefully protected during the resection of the lobe, pericarditis did not ensue. On the other hand, two patients in whom the pericardium seemed intact at the end of the operation both developed pericarditis at about the tenth day and then rapidly succumbed. In one of them a splashing pyopneumopericardium was noted clinically. At post-mortem examination a tiny perforation was noted in each pericardium, suggesting the site at which an artery clamp had been placed and then removed without ligature. Pericarditis has occurred, however, without demonstrable injury to the pericardium.

POSTOPERATIVE MANAGEMENT AND COMPLICATIONS

Bronchoscopy is performed routinely after lobectomy, even when intratracheal suction has been applied during the operation. The trachea and bronchi are cleared as much as possible of any secretions which might have been expressed from the diseased lobe during the manipulation and which might tend to obstruct a bronchus or cause infection.

The aspiration of air from the pleural cavity or the expansion of the lung by increase in the pressure within the anesthetic system is unnecessary and may be harmful by aiding the aspiration of viscid and infected material into peripheral bronchi from which it can be dislodged only with difficulty and where it may cause obstruction and infection. The rapidity with which the remaining lung expands to fill the hemithorax is striking and usually is complete by the third or fourth day. Negative pressure with drainage by connection of the drainage tube to a Woulfe bottle is sufficient and is maintained until several days after all evidence of a "swing" in the water column has ceased. The space about the drainage tube should be well sealed by adhesions after a few days, so that the application of increased negative pressure at this time can have little effect in aiding expansion of the lung, and may be harmful to the pedicle. If all is well, at the end of about the second week the drainage tube is cut short and lipiodol is injected to delineate the extent of the remaining cavity. As this cavity closes the tube is exchanged for a narrower one and then shortened. In practically all cases there is a small area of infection from the pedicle to the chest wall along the drainage tube,

but this clears and heals rapidly. Generalized empyema should not occur if proper precautions are taken against contamination during operation.

A small bronchial fistula makes its appearance usually near the end of the second week in about 60 per cent of the cases. Most often it closes spontaneously after a longer or shorter period, during which time a drainage tube must be kept in place. Closure may be facilitated by painting its orifice with 30 per cent silver nitrate internally through a bronchoscope or externally through the drainage tract.

In a few patients, especially in those in whom the remaining lobe is slow to expand, infection may occur in the small amount of fluid which usually forms above the unexpanded lobe. This should be aspirated frequently to make sure whether it remains sterile. If it becomes purulent this fluid should be drained through a separate closed intercostal drain. In some of these cases where the lung fails to expand but is uninfected, a chronic empyema remains and must be closed by an upper thoracoplasty (Fig. 2*A* and *B*). Similarly, in cases of upper lobectomy, the obliteration of the residual pleural space may be very slow and finally incomplete, even when aided by a phrenic nerve interruption. This may have to be completed by an apical thoracoplasty.

The question of postoperative massive collapse of the upper lobe is a puzzling one. The lobe may simply fail to re-expand after operation; or it may expand almost fully in several hours or one or two days after operation and then suddenly collapse. The use of intratracheal suction has been regarded as a possible factor in the causation of this collapse, especially after one recent case in which the anesthetist applied suction and the nonadherent upper lobe was noted to collapse as the operator watched it. In the attempt to re-expand it, it was necessary to apply a pressure of about 20 pounds per square inch before re-expansion occurred. But collapse of the lobe has occurred in cases in which suction was not used and in cases done under spinal anesthesia in which cough power was present even though perhaps impaired. Finally, collapse has occurred in a case in which the upper lobe was adherent over more than one-half its surface area and in which the adhesions were not destroyed at operation (Fig. 3*A* and *B*).

Frequently a collapsed lobe will re-expand slowly over a period of several months, with fluctuations in collapse and re-expansion. In others, a severe type of pulmonary infection with rapid excavation may result, necessitating removal of the remainder of the lung. Fortunately, however, this complication is uncommon.

The causative factor or factors of this massive collapse in this particular condition are at present uncertain. A notable fact is that this complication rarely occurs in children, who, in general, do very well.

Secondary hemorrhage may occur from the chest wall, either the main intercostal incision or the drainage orifice, from the pulmonary ligament, from the pedicle, or from some other part of the lung. If

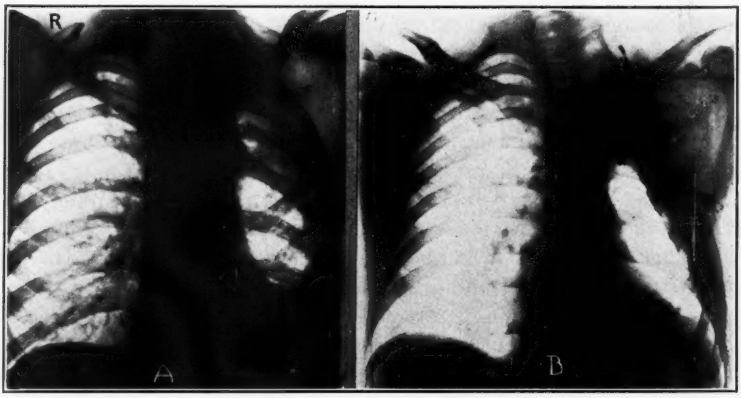


Fig. 2.—*A*, Showing a well-drained apical empyema following left lower lobectomy and failure of the upper lobe to fill the hemithorax. *B*, The same patient nine months later, following phrenicectomy and upper thoracoplasty. Lipiodol is seen in the residual extrapleural sinus.

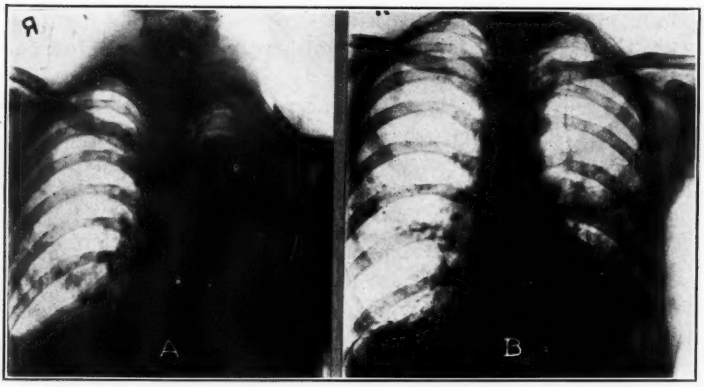


Fig. 3.—*A*, Three days after left lower lobectomy, film showing massive collapse of left upper lobe; the upper lobe had been found adherent over two-thirds of its surface at operation and adhesions left undisturbed. *B*, Same patient five weeks later showing complete re-expansion of the previously collapsed upper lobe.

severe sepsis occurs in a wound, hemorrhage may occur, usually from the place posteriorly where the rib has been divided and the intercostal artery exposed. For this reason some operators resect small portions of the ribs and ligate the vessels as they traverse the space, posteriorly. A pericostal suture may injure a vessel, and the bleeding may take place internally. For this reason careful placing of the pericostal sutures far below the lower border of the lower rib is essen-

tial. In one case a fatal hemorrhage occurred on the tenth day and at post mortem appeared to be from the pedicle. Careful dissection, however, revealed that a very small perforation had somehow been caused in the wall of the pulmonary artery branch to the remainder of the lung, probably by application of an artery clamp for bleeding in that region, removal of the clamp without ligature, and subsequent necrosis of the vessel wall.

The experience with postoperative hemorrhage in these cases is as yet insufficient to allow a dogmatic statement to be made concerning its treatment. Even if the patient has not lost much blood through the tube it may be obvious that severe hemorrhage has occurred. A blood transfusion should be given at once. The decision must then be made whether or not to reopen the chest. In one case severe hemorrhage occurred several hours after operation; the chest was reopened, and a bleeding vessel in the pulmonary ligament was ligated. The patient recovered. Two cases of hemorrhage several days after operation were reopened and no bleeding point found; both patients died despite transfusion. In two other cases the drainage tubes were clamped; the patients were given supportive treatment and both recovered. By reopening the chest, the patient is undoubtedly exposed to an added risk, but it seems indicated in cases of hemorrhage occurring soon after operation.

A phrenicectomy is usually performed three to six months after the operation. As has already been stated, it is considered desirable to have a fully functioning diaphragm in the period immediately after the operation in order to facilitate re-expansion of the remaining lung. The purpose of doing a phrenic evulsion during the late postoperative course is twofold: first to aid in closing any basal empyema cavity or sinus tract which may remain, and second to prevent the possible overexpansion of the remaining lung in the attempt to fill the entire hemithorax. If this is not controlled, it is thought that the overexpanded lung may become emphysematous and lead to further bronchiectasis. If a mild degree of bronchiectasis is present it is feared that this may become exaggerated.

CAUSES OF DEATH FOLLOWING OPERATION

When postoperative death does occur, the most common cause, by far, is infection in the remaining lung of the same or other side. No cases of suppurative mediastinitis have been encountered. Secondary hemorrhage, brain abscess, and suppurative pericarditis have each accounted for several deaths. Although acute pulmonary edema has occurred a number of times, necessitating proper treatment of the heart, cardiac failure as the cause of death soon after operation and not subsequent to prolonged postoperative pulmonary infection has occurred in one case only. This was a man, aged 30 years, with

bilateral lower lobe bronchiectasis of long standing and fairly marked emphysema of the remainder of the lungs. Because of the persistence of large daily amounts of malodorous sputum despite postural drainage for a long time, it was hoped to do a bilateral lower lobectomy. A left lower lobectomy was done first, but the day after the operation he developed progressive pulmonary edema to which he succumbed. Post-mortem examination revealed fairly severe myocardial degeneration, but no new pulmonary infection.

In conclusion, it must be stated that the views expressed in this paper on perhaps many points are the results of experience primarily, and will, no doubt, undergo more or less revision in the future.

The author wishes to express his sincere appreciation to Mr. J. E. H. Roberts for the exceedingly fine opportunity which was afforded him to assist at and study the cases.

The author wishes also to express his gratitude to Mr. F. Lee-Lander, Medical Registrar at the Brompton Hospital, for his very kind aid in studying the cases, and to all his other colleagues at the Brompton Hospital, whose attitude was so helpful during the period spent there.

REFERENCES

1. Roberts, J. E. H., and Nelson, H. P.: Pulmonary Lobectomy, Technique and Report of Ten Cases. Brit. J. Surg. **21**: 277, 1933.
2. Glass, A.: The Broncho-Pulmonary Segment With Special Reference to Putrid Lung Abscess. Am. J. Roentgenol. **31**: 328, 1934.
3. Nelson, H. P.: Irradiation of the Tracheo-Bronchial Lymphatic Glands. Lancet **2**: 1118, 1930.
4. Erwin, G. S.: Modern Technique in Bronchography. Lancet **1**: 1236, 1936.
5. MacMahon, C.: Prophylactic and Remedial Breathing and Physical Exercises. Brit. J. Tuberc. **28**: 184, 1934.
6. Nelson, H. P.: Postural Drainage of the Lungs. Brit. M. J. **2**: 251, 1934.
7. Magill, I. W.: Anesthesia in Thoracic Surgery With Special Reference to Lobectomy. Proc. Roy. Soc. Med. **29**: (Section of Anesthetics) 7, 1936.

MEDIASTINAL TERATOMATA

With Report of an Unusual Case

William T. Doran, M.D., and Charles W. Lester, M.D.,*
New York, N. Y.

MEDIASTINAL teratomata or their allied tumors, dermoid cysts, have been reported in the literature from time to time since 1825 when Gordon described a mediastinal cyst containing hair, sebaceous material, a rudimentary mandible, and seven teeth. However, in spite of our acquaintance with this tumor for more than a century, Hedblom, in 1933, could find only 191 cases including six of his own, to which Houghton added twenty-four more in 1936. With the development of thoracic surgery in recent years these tumors have been encountered more frequently and many have been successfully treated by operation. Fox and Hospers estimate that 80 per cent are essentially benign. Nevertheless, most of those reported, as in the case of the one we are reporting here, resulted fatally. For this reason, in describing our case, we are taking the opportunity of reviewing the salient features of the disease with the hope that the condition may be recognized before the size of the tumor and the involvement of the adjacent structures make surgery useless.

Embryologically these tumors are probably derived from the third branchial cleft and descend into the thorax with the heart and thymus. This would explain the fact that practically all of them start in the anterior mediastinum.

To follow the classification of Hedblom, these tumors may be divided into three groups: epidermoid cysts derived from ectoderm; dermoid cysts derived from ectoderm and mesoderm; and teratomata or teratoids derived from ectoderm, mesoderm, and entoderm. Most of them are derived from three layers and hence are teratomata, although many authors incorrectly speak of them as dermoids. They are predominantly cystic, and the cysts may be lined with stratified squamous, cuboidal, or columnar epithelium. Sebaceous material and hair are usually found in some of the cysts. In the solid portions bone, cartilage, teeth, muscle, both smooth and striated, nerve tissue, and occasionally rudimentary organs are found. Solid teratomata are not common but Fox and Hospers have reported two, both of which were malignant.

The tissues seem to be well differentiated and adult in type but they should all be considered as potentially malignant. Sometimes the

*From the Fourth Surgical Division, Bellevue Hospital, New York City, Carl G. Burdick, M.D., Director.

Received for publication December 13, 1937.

tumor acts in a malignant fashion from the start and these are usually found in the younger age groups. Malignancy appearing in the so-called cancer age is probably a malignant degeneration of one or more elements, usually epithelial, which have existed in a benign state for many years.

In size the teratomata vie with the lipomas for the distinction of being the largest mediastinal tumors. Our own tumor weighed 5,320 gm. and ranks among the largest. Yet it is small compared to the solid teratoma reported by Fox and Hospers which weighed 9 kg. and which they claim to be the largest on record. Apparently they have overlooked the tumor reported by Nandrot thirty years ago. Nandrot did a thoracotomy and incision of a mediastinal tumor for relief of dyspnea and evacuated 3 kg. of sebaceous material. The patient died two days later and at autopsy they found that only one loculus of the tumor had been opened. The tumor removed at autopsy plus the material removed at operation weighed 11 kg. This puts two teratomata ahead of the lipoma reported by Leopold which weighed 8 kg., a consideration really of secondary importance. What actually matters is that mediastinal teratomata may be of enormous size. That they are not all in the category of tremendous tumors is obvious. They must all be small to begin with and some remain small throughout life, being found quite unexpectedly at autopsy. Others are of moderate size when discovered but may grow rapidly while under observation. Nothing need be done about the small tumors and nothing can be done about the large ones, but most of the others can and should be subjected to surgery while they are still in the operable stage.

Teratomata are found predominantly in the younger age groups. According to Hedblom 33.5 per cent occurred in the third decade and 68.5 per cent occurred in the first three decades.

The symptoms for the most part are those due to intrathoracic pressure. Dyspnea is present in nearly all and may be due as much to interference with the pulmonary circulation by pressure on the pulmonary vessels as to encroachment on the lungs. Cough is the next most common symptom and is usually nonproductive. Occasionally a cyst may rupture into a bronchus, and then hair and sebaceous material may be expectorated. Cyanosis and swelling of the face and neck are not infrequent but are late symptoms, as is pain.

The physical signs are those of a large nonaerated mass in the thorax. The dullness and absence of voice and breath sounds may lead to aspiration of the chest under the mistaken diagnosis of pleural effusion. Pleural effusion, however, is not infrequent and is due to stasis. Sometimes the tumor may push out above the sternum as happened in the first case on record. Edema and cyanosis of the face and

neck are striking when the tumor compresses the superior vena cava, but strangely enough dilation of the neck veins is unusual.

X-ray examination is essential in making a diagnosis. A large lobulated tumor arising in the anterior mediastinum suggests teratoma, among other things. If the x-ray film shows the presence of bone or teeth, the diagnosis is certain. Without that feature other tumors must be considered.

Lymphosarcoma, Hodgkin's disease, ganglioneuroma, aneurysm, and lipoma must be excluded as well as the more unusual tumors of the thymus, so ably described by Symmers. The first two conditions respond noticeably to deep x-ray therapy, while teratoma is little, if any, affected. The Wassermann test will aid in differentiating aneurysm from the other conditions. Ganglioneuroma usually arises posteriorly. Lipoma cannot always be excluded, but if the tumor is large enough to give symptoms, there is no objection to making the diagnosis on the operating table. The other thymus tumors are malignant and invade the adjacent structures early.

The treatment is surgical. Irradiation is not effective. The approach depends on the site of the tumor, for while teratomata originate in the anterior mediastinum their subsequent development may cause them to lie in almost any part of the chest. Sharp dissection is necessary to free the tumor from the pericardium, great vessels, and other structures, so operation should be undertaken only by one accustomed to thoracic surgery. Occasionally the exigency of the situation permits only marsupialization and incision of the cyst, but the certainty that infection will follow makes this an unsatisfactory procedure, although Lilienthal reports a case successfully treated in this manner. More recently Heuer and also Harrington have discussed the details of the operation for removal of these mediastinal teratomata.

CASE REPORT*

The patient, a white man 24 years of age, was admitted to the Fourth Surgical Division of Bellevue Hospital Jan. 10, 1935, complaining of pain in the right chest of three months' duration and swelling of the neck of one month's duration.

The family history and past history were irrelevant. He had never suffered from any serious illness and had had no operations. He was employed as a clerk.

The present history began three months before admission with pain in the right side of the chest in the region of the third rib. During this time he had been bothered with slight dyspnea and slight cough with mucoid sputum but no hemoptysis. For the past month he had noticed some swelling in his neck. He sought hospital care for the gradual but steady increase in all these symptoms.

Physical examination showed a white man about 24 years old, fairly well developed and nourished. The right side of his chest was limited in movement and flat to percussion throughout. Breath and voice sounds were diminished in this

*This case is entered in the registry of thoracic tumors of the American Society for Thoracic Surgery.

region and fremitus was absent. Just above the fourth rib anteriorly there was a friction sound. The neck was moderately and symmetrically enlarged. In the left axilla there were a few palpable lymph nodes. The limit of cardiac dullness was well over towards the left axilla.

X-ray examination showed a dense shadow involving the entire right side of the thorax and pushing the heart and mediastinum well over to the left.

Bronchoscopic examination revealed the right main bronchus to be narrowed and distorted from the external pressure of a tumor mass.

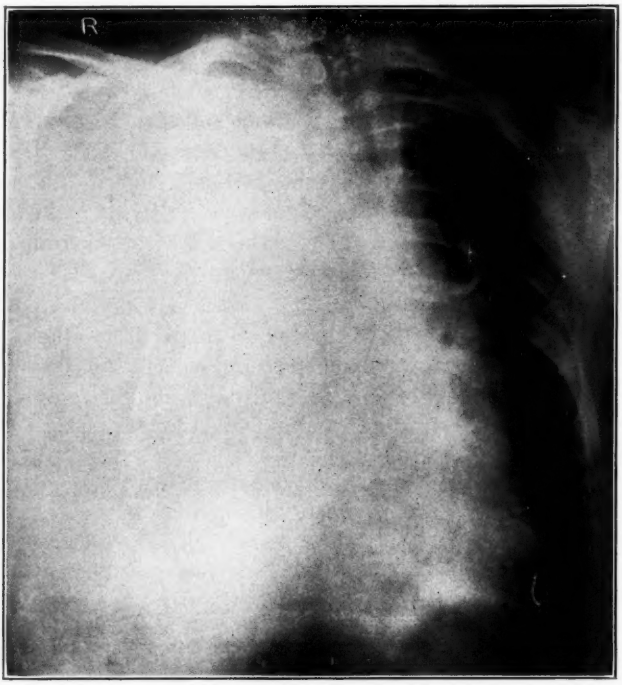


Fig. 1.—X-ray picture of chest.

The condition was considered inoperable, and deep x-ray therapy was commenced at once. Between January 14 and February 20 he had fourteen treatments. There seemed to be a little improvement at first but this was only temporary and the course continued steadily downhill. On January 24, 1350 c.c. of serosanguineous fluid was aspirated from the right chest, and on March 10, 1000 c.c. was again aspirated. Examination of the centrifuged sediment did not show any tumor cells but culture of the last aspirated fluid showed hemolytic streptococcus. Aspiration biopsy on January 30 and biopsy of an inguinal node removed March 9 gave no clue as to the tumor.

During his stay in the hospital the patient became progressively weaker. The dyspnea increased and the edema which involved only the neck on admission spread to the face, chest wall, and right arm. The temperature, normal at first, became elevated each night and eventually reached 103° F. daily. The heart action became

faster and weaker. Death occurred March 14, 1935, nine weeks after admission and about five months after the onset of his symptoms.

Report of Autopsy.—Removal of the chest plate allowed the escape of about 2 L. of serosanguineous fluid. Occupying the right pleural cavity was a large, hard, irregular mass extending from the diaphragm to the apex of the thorax. Fibrous adhesions bound it to the parietal pleura and to the right lung which was collapsed and adherent to the posterior and mesial surfaces of the tumor. The heart and mediastinal contents were completely displaced into the left side of the thorax, and the lower lobe of the left lung was partially collapsed.

Fig. 2.—Photograph of tumor after cysts had been evacuated and specimen fixed in formalin.

Tumor.—The tumor measured 30 by 40 by 20 cm. and weighed 5,320 gm. It had an irregular outline and was encapsulated, although the surface was covered with fibrous adhesions. On palpation it was firm but contained some definite fluctuant areas and other areas of stony hardness. On section of the tumor a variety of cysts were opened. Some contained sebaceous material and hair; others were filled with gelatinous mucus; and the remainder contained a mucopurulent substance. The solid part of the tumor seemed to be composed of dense connective tissue in which could be distinguished bone tissue and cartilage. No teeth or bones as such could be recognized, the calcified and bony tissue being scattered about in small collections.

Lungs.—The right lung was completely collapsed and atelectatic. Its cut surface was congested and showed a few areas of consolidation in the lower lobe. The right bronchus was stenosed and moderately filled with mucopurulent material. The left lung had numerous areas of emphysema at its apex. It was crepitant throughout with the exception of the lower lobe which was partially collapsed. On section the upper lobe appeared normal but the lower lobe was congested and edematous.

Heart.—The heart weighed 300 gm. The auricles were of normal appearance. The wall of the left ventricle had a thickness of 10 mm. and the right ventricular wall of 5 mm. The valves and the coronary arteries were not abnormal.

Gastrointestinal Tract.—The mucosa of the stomach and duodenum had numerous small hemorrhagic areas without ulceration. No other abnormalities were noted.

Liver.—The liver weighed 1810 gm. and appeared to be congested but was otherwise not unusual.

Gall bladder, spleen, kidneys, and urinary bladder were not abnormal.

Microscopic Examination of the tumor was done by Dr. Douglas Symmers. Numerous sections taken from different parts of the tumor showed a disorderly arrangement of structures representing all the primordial layers—cysts or cystlike formations lined by stratified epithelium of the squamous type, or by low cuboidal epithelium or by low cylindrical epithelium, some filled with mucoid substance, others with degenerate epithelial cells of the squamous type, and slitlike or dilated spaces lined by endothelium, together with pigmented cells evidently derived from the choroid, smooth muscle fibers, cartilage, bone, hair follicles, brain tissue, and chorionic villi.

Fig. 3.—Photomicrograph of tumor showing cysts lined with stratified squamous and columnar epithelium, bone, connective tissue, and pigmented cells from the choroid.

COMMENT

Death in this case was apparently caused by the mechanical pressure exerted by an enormous tumor, otherwise benign. The tumor, one of the largest teratomata on record and the largest teratoma in the registry, must have been present for some time as the adult nature of the tissues of which it was composed can hardly be expected to display the rapid growth characteristic of malignancy; yet the duration of the symptoms was relatively short. The adaptability of the heart and lungs to encroachment is a striking but, in the case of intrathoracic tumors, an unfortunate attribute. This should always be remembered and thorough investigation should be undertaken at the first evidence of symptoms.

REFERENCES

Fox, J. P., and Hospers, C. A.: Solid Teratoid Tumors of the Anterior Mediastinum, Am. J. Cancer **28**: 273, 1936.

Gordon, J. A.: A Case of Tumor in the Anterior Mediastinum Containing Bone and Teeth, Med. Chir. Trans. **13**: 12, 1825.

Harrington, S. W.: Surgical Treatment in Eleven Cases of Mediastinal and Intrathoracic Teratomas, J. THORACIC SURG. **3**: 50, 1933.

Hedblom, C. A.: Intrathoracic Dermoid Cysts and Teratomata, J. THORACIC SURG. **3**: 22, 1933.

Heuer, G. J.: The Surgery of Mediastinal Dermoids, Ann. Surg. **90**: 692, 1929.

Heuer, G. J., and Andrus, W. De W.: Surgical Treatment of Mediastinal Tumors, Surg. Gynec. & Obst. **63**: 469, 1936.

Houghton, J. D.: Malignant Teratoma of the Mediastinum, Am. J. Path. **12**: 349, 1936.

Leopold, R. S.: A Case of Massive Lipoma of the Mediastinum, Arch. Int. Med. **26**: 274, 1920.

Lilienthal, H.: Extirpation of Dermoid Cyst of Mediastinum, S. Clinics N. America **1**: 1533, 1921.

Nandrot, C.: Contribution a l'etude des kystes dermoides du mediastin anterieur, Paris Theses, 1907.

Symmers, D.: Malignant Tumors and Tumor-Like Growths of the Thymic Region, Ann. Surg. **95**: 544, 1932.

TUBERCULOUS LESION OF LUNG ELIMINATED BY SUPPURATIVE PUTRID INFECTION, WITH RECOVERY

SAMUEL BERG, M.D., AND RICHARD H. DIEFFENBACH, M.D.*
NEWARK, N. J.

THE association of pulmonary tuberculosis with suppurative lung lesions such as abscess or gangrene has been recognized for many years. Laennec[1] noted that tuberculous cavity walls could undergo gangrenous changes, and referred to earlier publications in which this complication was described. But much literature pertaining to the simultaneous occurrence of these two conditions published during the nineteenth century must be viewed with skepticism because the diagnosis of tuberculosis was made clinically and without laboratory support.[2] Nevertheless, many clinicians noted the undoubted occurrence of these two diseases in association, and recognized what has been emphasized in recent years: that the form of tuberculosis which appears actively after suppurative conditions is usually of the acute fulminating type hematogenously disseminated.

The manner in which anaerobic and tuberculous infections are associated has been the subject of numerous classifications, all of which can be summarized briefly as follows:

1. Active pulmonary tuberculosis followed by pyogenic infection of the lung parenchyma, each taking its independent course, or the latter aggravating the former.

2. Pyogenic infection of the lung parenchyma followed by active pulmonary tuberculosis, the former activating or aggravating the latter directly or indirectly.

3. Pyogenic infection of the lung parenchyma followed by pulmonary tuberculosis resulting from exogenous superinfection or primary infection.

The more important references to the literature of the present century can be found in a recent article by Murray.[3] The case to be described appears to be the only one in which an ulcerocaseous tuberculous process is completely involved in an extensive gangrenous† process.

*From the surgical service of Dr. Dieffenbach, Newark Memorial Hospital.
Received for publication Sept. 23, 1937.

†Although abscess and gangrene are considered by some as two distinct processes, this differentiation is still the subject of considerable discussion as applied to lung involvement. For the purposes of this paper this differentiation is immaterial, so long as it is understood that the fundamental consideration is the anaerobic infection. In this sense the words abscess and gangrene are used interchangeably.

CASE REPORT

W. G., aged 43 years, a mechanic, gave an antecedent history of no significance. Early in August, 1934, he noted the gradual onset of cough, slight expectoration, loss of weight, malaise, and weakness, and was treated by his physician for a "cold" during the entire month. In September symptoms became worse, temperature rose to 101° F., and slight hemoptysis occurred once. Sputum examined on one occasion did not reveal the presence of acid-fast bacilli. After a month of bed rest the patient was discharged as cured of pneumonia. But within a short time cough and expectoration returned, and when a roentgenogram taken on October 28, 1935 (Fig. 1), revealed a cavity, the patient came under the care of the authors three months after the onset of illness. The lung fields were without notable changes except in the left subclavicular region, where a definite cavity drained into a bronchus. Corresponding physical signs were present. Sputum averaged about a tablespoonful a day and was odorless. Temperature was normal. Within the next two weeks eight specimens of sputum were examined, and three were reported to contain scant numbers of acid-fast bacilli by two different examiners. The diagnosis was then made of caseous pneumonic tuberculosis, of an excavated infiltrate conforming in every way with Assmann's early subclavicular lesion. The patient was put to bed at absolute rest at home for observation as to progress of the infection.

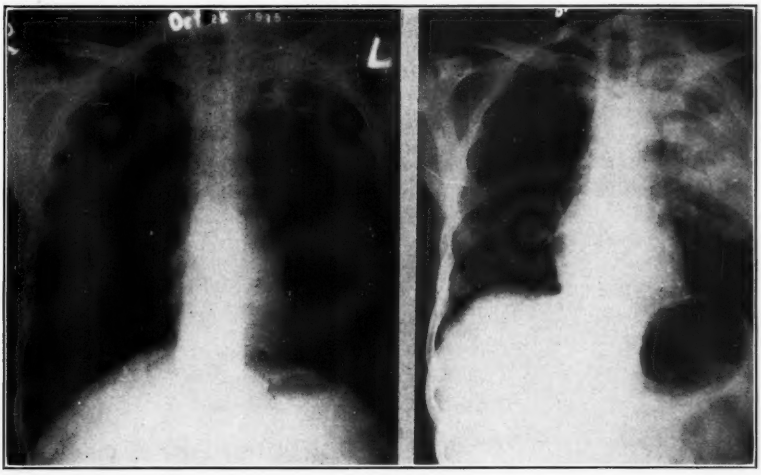


Fig. 1. Fig. 2.

Conservative treatment was considered advisable because the sputum showed a low count according to the Gaffky scale, because it was mucoid rather than watery, and because it was scant in amount, all of which are factors not conducive to active bronchiogenic spread. Also, subclavicular infiltrates, even those excavated by caseous changes, often progress to spontaneous cure.[4, 5]

Accordingly, the patient remained in bed, and fared well for two weeks. Then a high concentration of coal gas from a stove caused violent and prolonged cough with hemoptysis. Two days later the patient experienced chill and sticking pain in the left subclavicular region. Râles and bronchovesicular breath sounds became audible in this area, temperature and pulse became elevated, and the sputum increased markedly in amount, was greenish, mucoid, and definitely foul. Repeated

sputum examinations from this time on were negative for acid-fast organisms. Neither spirilla nor fusiform bacilli could be seen, but a gram-negative streptococcus was cultured under anaerobic conditions. A roentgenogram on Jan. 17 (Fig. 2) was interpreted by the radiologist as showing pneumonic extension with complicating abscess formation. The patient was then admitted to the hospital.

Fig. 3. Fig. 4.

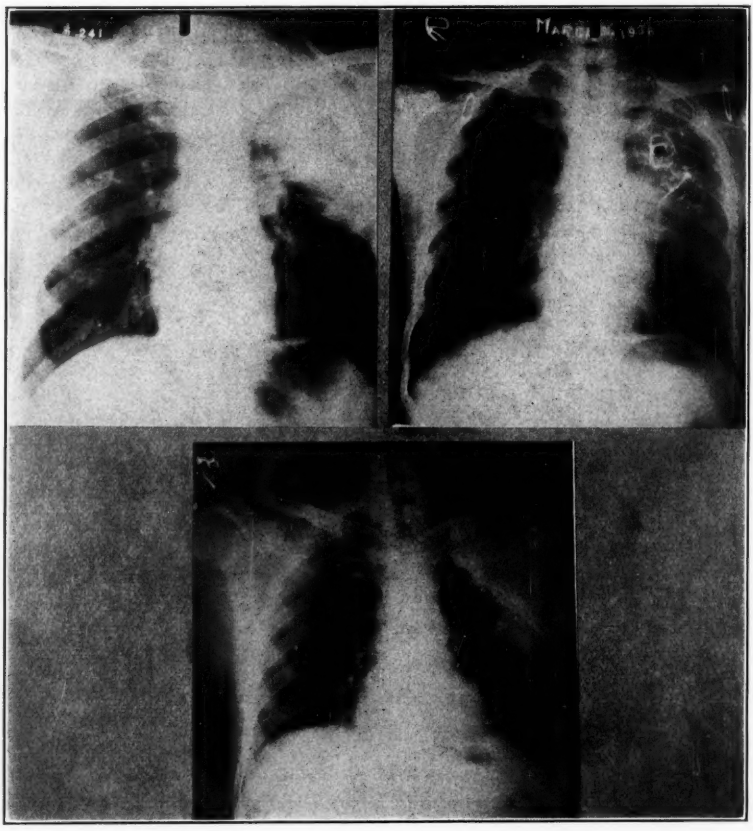


Fig. 5.

The patient ran a septic temperature, lost considerable weight, and became anemic (Hb 63 per cent). The fingers began to show clubbing. Radiologic examination on February 5 revealed a large cavity in the left subclavicular region with a fluid level near its upper border (Fig. 3). Open surgical intervention was decided upon in spite of the tuberculous infection. On March 3 the cavity was drained after resecting a two-inch portion of the second rib anteriorly and then packed with iodoform gauze. The cavity decreased from the size of an orange to that of a plum. Examination of its interior through a cystoscope showed clean granulation tissue, and direct smears did not contain acid-fast organisms. Plates made after blowing bismuth subcarbonate and injecting iodoform suspension into the cavity revealed

extensive bronchiectasis (Fig. 4). The general condition improved considerably; temperature and pulse dropped almost to normal, and weight increased from 90 pounds on February 22 to 110 pounds two months later. Early in May a regular first stage thoracoplasty (four upper ribs) was performed to complete closure of the cavity. Within a year the patient showed complete healing, weighed 130 pounds, and had resumed his occupation (Fig. 5).

DISCUSSION

Acid-fast organisms were not seen in the sputum after the onset of gangrene. One would expect to find them in tuberculous material eliminated with other tissue involved in a gangrenous process; but Neuhof and Wessler[4] have observed that "a putrid lung abscess occasionally occurs in the midst of unrecognized pulmonary tuberculosis. The latter may not be recognized because we have not, up to the present, found tubercle bacilli in the sputum while the putrid infection exists in such cases." It might be of interest to contemplate the relationship between the growth of tubercle bacilli and the conditions which permit anaerobic infections. Tubercle bacilli are strict aerobes, and lack of oxygen for only a short time suffices to inhibit their growth or destroy them.[5] The putrid types of lung abscess and gangrene result from the rapid propagation of anaerobic organisms under anaerobic, or at least deficient oxygen, conditions; total involvement of tuberculous lesions in the gangrenous process would cause rapid destruction of tubercle bacilli, at least beyond tinctorial recognition.

There is the possibility that the acid-fast rods seen on three occasions before the onset of gangrene were not actually tubercle bacilli. But certainly their presence in a patient with an excavating lesion in the subclavicular region accompanied by odorless sputum is presumptive evidence that they are tubercle bacilli, regardless of their scant or infrequent appearance, and under similar circumstances one would hardly demand such proof by guinea pig inoculation. There was no question as to the onset of putrid gangrene; it began two days after a pulmonary hemorrhage with severe general symptoms, sticking chest pain, profuse greenish and very foul sputum, subpleural excavation, and clubbing of the fingers.

Rankin and Weigel,[6] by direct inspection through an opening made by resection of part of the second rib anteriorly directly over a tuberculous cavity, observed its sterilization during the application of bacteriostatic dyes. Within two months this change took place, and scrapings of the wall revealed very scant numbers of acid-fast bacilli which eventually disappeared altogether. Repeated roentgenograms showed marked shrinkage of the cavity until only a sinus remained at the time of reporting. What surgery had accomplished by dye applications in their case, nature accomplished by anaerobic gangrene in our case.

SUMMARY

A patient with a subclavicular cavity of several months' duration diagnosed tuberculous by the presence of certain symptoms and the absence of others, and by the presence of acid-fast organisms in the sputum on several occasions, developed acute pulmonary gangrene over a portion of lung extensive enough to involve the tuberculous area in toto. Surgical drainage followed by thoracoplasty has eventuated in complete recovery. This case, which differs from all other reported cases of these two conditions occurring simultaneously only in its favorable outcome, is reported for the purpose of calling attention to the fact that if other patients with tuberculous lesions accompanied by a low Gaffky sputum count should develop a superimposed gangrene, the prognosis need not be hopeless as considered heretofore, and that treatment in accordance with modern surgical methods holds out some expectation of complete recovery.

REFERENCES

1. Laennec, R. T. H.: Traite de l'auscultation mediate, 1891.
2. White, J. B.: Pneumotomy for Relief of Tuberculous Abscess and Gangrene of the Lungs: Recovery, Medical News **62**: 38, 1893.
3. Murray, F.: Lung Abscess and Tuberculosis, Am. Rev. Tuberc. **33**: 236, 1936.
4. Neuhof, H., and Wessler, H.: Putrid Lung Abscess, J. THORACIC SURG. **1**: 637, 1932.
5. Novy, F. G., and Soule, M. H.: Respiration of Tubercle Bacilli, J. Infect. Dis. **36**: 168, 1925.
6. Rankin, H. P., and Weigel, B. J.: Chemical Sterilization of Large Tuberculous Cavities, J. A. M. A. **82**: 460, 1924.

THE CLINICAL AND ROENTGENOLOGIC FEATURES OF PULMONARY ABSCESS LOCATED IN THE SUPERIOR DIVISION OF THE LOWER LOBES

DAN W. MYERS, M.D., AND BRIAN BLADES, M.D.
ST. LOUIS, MO.

THE predilection of putrid pulmonary abscess for the right lower lobe of the lung has been noted by many observers. As Levitin and Brunn[1] have shown, however, each of the voluminous lower lobes is composed of two divisions, the superior and inferior, exhibiting distinct embryologic and anatomic features. The same investigators referred briefly to the superior division of the lower lobe as the most common site of abscess,[2] but we have been unable to find more detailed studies concerning the frequency of localization of suppurative processes in the two parts of the lower lobe. A review of the cases of abscess of the lung observed at the Barnes Hospital Chest Service during the past three years revealed a high incidence of involvement of the apical portion of the lower lobe and demonstrated certain clinical and roentgenologic features dependent upon that particular position.

TABLE I

THE LOCATION OF THE LESION IN SIXTY-NINE CASES OF PULMONARY ABSCESS

LOWER LOBE LESIONS		UPPER AND MIDDLE LOBE LESIONS		
Right lower lobe:		Right middle lobe	2	
Superior division	13	Right upper lobe	8	
Inferior division	14	Left upper lobe	8	
Left lower lobe:				18
Superior division	5	Unlocalized	10	
Inferior division	6	Pyopneumothorax	3	
Totals:				13
Superior division	18			
Inferior division	20			
Total	38	Total		31

During the past three years we have seen sixty-two cases of nontuberculous pulmonary abscess. Suppurative processes occurring as a consequence of bronchial obstruction produced by tumor and those cases of septicemia in which there were multiple pyemic foci in the lungs have not been included. The distribution of the lesions is given in Table I. The percentage of instances in which localization to the superior division of

From the Chest Service of Barnes Hospital and the Departments of Medicine and Surgery, Washington University School of Medicine, St. Louis.
Received for publication December 12, 1938.

the lower lobe occurred is all the more striking when one considers that the inferior division constitutes the greater bulk of the lobe, including all that lung tissue supplied by the ventral, axillary, posterior, and mesial divisions of the bronchus to the lower lobe.

The apical division of the lower lobe was involved in 32 per cent of the fifty-six cases in which precise localization was possible, and 47 per cent of the lower lobe lesions occurred in the superior division.

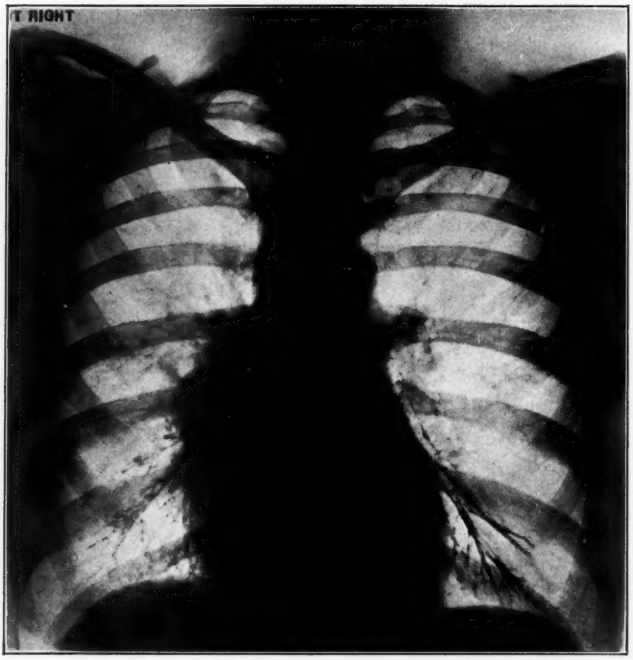


Fig. 1A.

Fig. 1.—*A*, Case 1. Posteroanterior roentgenogram of chest. Lesion seen at level of right hilum erroneously diagnosed central abscess. Artificial pneumothorax recommended. *B*, Case 1. Pyopneumothorax which developed during pneumothorax therapy. Patient died. Autopsy revealed rupture of pulmonary abscess located peripherally in the superior division of the right lower lobe.

The recognition of lesions in the superior divisions of the lower lobes is not only of academic interest but is of great practical importance in determining the proper treatment. Authoritative opinion[3] recognizes two varieties of lung abscess in respect to the location—the so-called central abscess situated near the hilum of the lung and the peripheral lesion which is not drained by a large bronchus. Neuhof and Touroff[4, 5] have recently attacked the concept of central abscess, and according to their belief the suppurative process always lies in close proximity to the visceral pleura. It is not our intention to discuss this controversial point

but to demonstrate how abscesses situated near the periphery of the lung in the superior division of a lower lobe may easily be mistaken for centrally placed lesions.

In the past, and perhaps to a less degree at the present time, artificial pneumothorax has been considered proper treatment for a pulmonary abscess situated near or at the hilum in a location apparently inaccessible for surgical drainage. If a lesion in the superior division of the lower lobe is mistakenly diagnosed as a central abscess, surgical drainage is likely to be delayed, and, if pneumothorax is used, the serious complications resulting from its employment in peripheral lesions may occur.

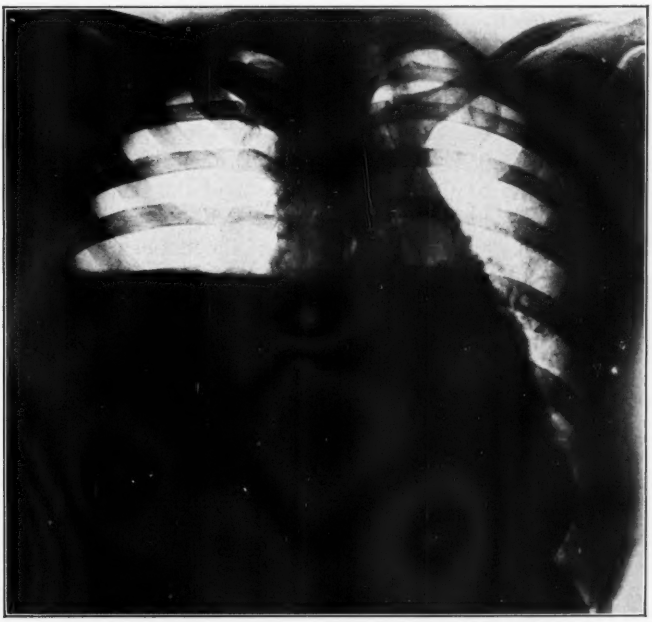


Fig. 1*B*.

LOCALIZING SIGNS IN APICAL DIVISION LESIONS

The importance of recognition of the true situation of apical division abscesses has been emphasized. On physical, roentgen, and bronchoscopic examinations these lesions usually present certain distinctive features. It has been our practice to carry out all these procedures and then correlate the data obtained.

Although the physical examination is notoriously unreliable, definite findings were present in the majority of our cases in which the process was located in the superior division of the lower lobe. The abnormal signs were noted over the posterior aspect of the thorax in an area situ-

ated between the spine and the posterior axillary line, and between the levels of the fifth and ninth ribs. In one instance, the abscess developed while the patient was under observation in the hospital, and in this case physical findings were not demonstrable until after the first week of illness. Impairment of the percussion note was the most valuable physical sign for purposes of localization. On occasion auscultation revealed frank evidences of consolidation, and the position of the lesion could then be defined with comparative ease. Râles were almost invariably noted when repeated examinations were made, but they were often widely transmitted and were regarded therefore as an unreliable localizing sign. Occasionally marked impairment of resonance and striking diminution in transmission of fremitus, voice, and breath sounds were present, simulating the changes produced by an encapsulated empyema. These findings result when the abscess lies in close apposition to the visceral pleura and does not possess an open bronchial communication; under these conditions sounds are reflected just as they are by pleural fluids. Encapsulated empyemas ordinarily become localized between the lobes of the lung in the axillary area, or in the lower portion of the thorax; therefore, when the physical signs of an apical division abscess simulate the presence of encysted pleural fluid, the location of the findings should suggest the correct diagnosis.

Bronchoscopic examination provides valuable information since it permits determination of the source of the purulent secretion. Kramer and Glass[6] have outlined areas on the chest wall overlying the pulmonary segments supplied by each bronchial division, and Neuhof and Touroff have recently commented on the extraordinary accuracy of localization of abscess attained through application of this principle. The superior division of the lower lobe is supplied by its own bronchus, arising on the right side from the posterior aspect of the stem bronchus at approximately the same level as the division to the middle lobe, which takes its origin anteriorly. On the left, the apical division bronchus arises from the posterior wall of the main bronchial trunk approximately 1 cm. distal to the opening of the bronchus to the left upper lobe. The chief obstacles encountered in localization with the bronchoscope are: first, that the abscess may not have established communication with a bronchus so that no pus can be found or, second, that the purulent drainage may be so profuse as to make determination of its source impossible. Exploration of the upper lobe bronchi and their divisions is often so difficult a technical procedure that the bronchoscopist cannot decide which of the secondary branches leads to the suppurating bronchopleural segment.

Although roentgen examination has usually furnished the most reliable guide in the localization of pulmonary abscesses, the chief source of error in diagnosis of lesions in the superior divisions of the lower lobes is found in improper interpretation of x-ray films of the chest taken in the posteroanterior projection. Frontal plane exposures frequently give

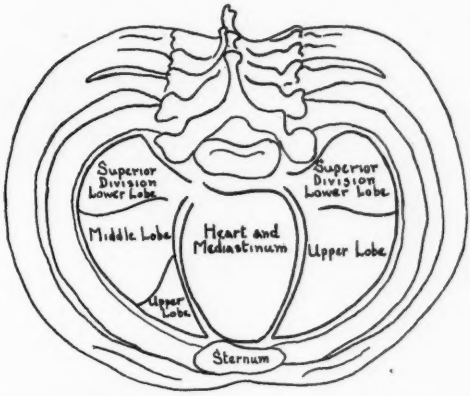


Fig. 2.—Diagrammatic representation of the pulmonary lobes in sagittal section at the level of the seventh thoracic vertebra. Note position of superior divisions of the lower lobes in the vertebral gutter.

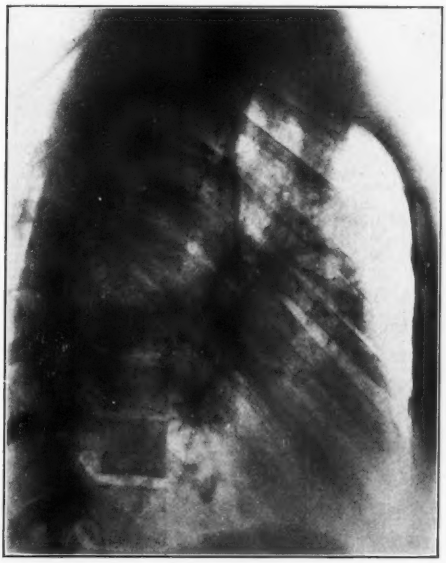


Fig. 3.—Case 2. Lateral roentgenogram of chest. Proved case of abscess in superior division of right lower lobe. Slight rotation of patient from true lateral position, however, would seem to place abscess at hilum. A satisfactory lateral projection is seen in Case 3, Fig. 4 *A*.

Fig. 4A.

Fig. 4.—*A*, Case 3. Roentgenogram demonstrating the actual posterior position of a lesion in the superior division of the lower lobe taken in true lateral projection: *B*, abscess in superior division left lower lobe. Lateral bronchogram showing failure of lipiodol to enter involved area.

the false impression that lesions involving the apex of the lower lobe are situated at the hilum of the lung. A roentgenogram in the lateral view will often reveal the true situation of the lesion but minor errors in radiologic technique will add to the confusion. Even in a true lateral projection marked convexities of the posterolateral chest wall will create the illusion that a process in the paravertebral gutter is situated at the hilum (Fig. 2). When the x-ray films appear to confirm an impression of central abscess, we turn to the bronchoscopic and physical findings in an attempt to define the position of the lesion more accurately.

Body section radiography, with the aid of the laminagraph designed by Kieffer, was carried out on many of our patients with pulmonary abscesses under the supervision of Dr. Sherwood Moore, who developed the apparatus, with the object of demonstrating cavities not visualized in the conventional roentgenogram. Frequently the laminagraph was successful in revealing hidden abscess cavities, thus constituting an important diagnostic advance. Recently we have begun to realize that the

Fig. 4B.

device is of great assistance in determining the relationship of the lesion to the chest wall. A series of x-ray films is taken with the laminagraph set at different focal planes, so that the resultant plates constitute serial radiographic sections from front to back of the chest. The focus of the machine is remarkably sharp, and it is comparatively simple to determine within a few centimeters the distance between the lesion and either the anterior or posterior thoracic wall by observing the level of the focal plane which gives the most distinct shadow of the abscess. Lesions in the apical division are usually best visualized in the anteroposterior laminagram when the focal level is adjusted at a distance between 6 and 8 cm. from the radiographic table on which the patient lies supine.

Lipiodol bronchograms have often given us additional information, not provided by roentgenograms without contrast filling of the bronchial tree. It is rare indeed to fill the abscess cavity with iodized oil administered by the supraglottic or aspiration method, and the lesion is usually mapped out by a process of exclusion, the area which the contrast medium has not entered representing the site of the abscess. Often a definite blockage of the bronchus leading to the abscess may be demonstrated, as shown in Fig. 4, so that anyone familiar with the roentgen

anatomy of the bronchial tree may readily identify the bronchus and thus determine the bronchopulmonary segment containing the suppurative process. In cases of lung abscess we attempt to fill the bronchi on the involved side of the thorax only, and x-ray films are taken in lateral and posteroanterior positions. A special effort should be made to fill the apical division bronchus by having the patient lean far backward as the iodized oil flows down the main bronchus under fluoroscopic vision. We have not observed any reactions following bronchography, but this procedure has been reserved for the more chronic cases in which the demonstration of an associated bronchiectasis may alter both prognosis and treatment.

SUMMARY

The distribution of pulmonary abscess has been studied in a series of sixty-nine cases. Involvement of the superior segments of the lower lobes of the lung occurred with striking frequency, the lesion being situated in this location in 32 per cent of the cases. Forty-seven per cent of the lower lobe abscesses occurred in the apical division. Lesions in this location may be improperly regarded as central abscesses, and a case demonstrating the danger of confusion is illustrated (Case 1). Localization of a pulmonary abscess should be undertaken with scrupulous care. The various procedures concerned are discussed.

REFERENCES

1. Levitin, J., and Brunn, H.: Study of Lower Lobe of Lung; Explanation of Roentgenologic Shadows, Arch. Int. Med. **57**: 649, 1936.
2. Levitin, J., and Brunn, H.: Study of Roentgenologic Appearance of Lobes of Lung and Interlobar Fissures, Radiology **25**: 641, 1935.
3. Graham, E. A., Singer, J. J., and Ballon, H. C.: Surgical Diseases of the Chest, Philadelphia, 1935, Lea and Febiger.
4. Neuhof, H., and Touroff, A. S. W.: Acute Putrid Abscess of the Lung, Surg. Gynec. & Obst. **63**: 353, 1936.
5. Neuhof, H., and Touroff, A. S. W.: Acute Putrid Abscess of the Lung, Surg. Gynec. & Obst. **66**: 837, 1938.
6. Kramer, B., and Glass, A.: Bronchoscopic Localization of Lung Abscess, Ann. Otol., Rhin. & Laryng. **41**: 1210, 1932.

MEDIASTINAL EMPHYSEMA AS A COMPLICATION OF ARTIFICIAL PNEUMOPERITONEUM*

ANDREW L. BANYAI, M.D., AND GEORGE H. JURGENS, M.D.
WAUWATOSA, WIS.

ARTIFICIAL pneumoperitoneum for the treatment of pulmonary tuberculosis is attaining a gradually increasing interest. As it had been expected, when dealing with a large number of cases treated by this method, one is likely to encounter some complications hitherto not reported in the medical literature. One of these is mediastinal emphysema.

The majority of authors writing on their experiences with this method advocated a technique with the point of injection three finger-breadths below and to the left of the umbilicus. Other sites that were recommended for the injection were: (1) below the umbilicus in the middle line; (2) just lateral to the left rectus abdominis muscle immediately below the costal margin; (3) the corresponding site on the right side; (4) the right lower quadrant; and (5) the subphrenic route—the point of entrance of the needle is above the costal margin but below the costophrenic reflection of the pleura.

We have used pneumoperitoneum for the treatment of intestinal tuberculosis since 1929 and for the treatment of pulmonary tuberculosis since 1931. Although the subphrenic route was used for treating tuberculous bowels before our work, we were led to adopting and recommending it for the treatment of pulmonary tuberculosis by an accident while treating one of our pneumothorax patients. This case was reported in detail previously.[1] The patient had a far advanced tuberculosis, involving the upper and lower one-thirds of the right lung, and the entire left lung. Because attempts at artificial pneumothorax on the left side failed, an exeresis of the left phrenic nerve was performed. Subsequent severe hemorrhages forced us to try artificial pneumothorax again. To the surprise of the patient and the attending staff, 1000 c.c. of air was injected without difficulty. A roentgenogram taken after this treatment showed that an artificial pneumoperitoneum was given instead of pneumothorax. The intervention proved to be effective therapeutically in that it controlled the hemorrhage. Then, because of the facility with which air was introduced into the peritoneal cavity, it was decided to use this route for treating our pulmonary tuberculosis cases in whom no other mechanical measure seemed to be feasible or practicable.

*From Muirdale Sanatorium, Wauwatosa, Wis. and from the Department of Medicine, Marquette University Medical School, Milwaukee, Wis.
Received for publication January 24, 1938.

As it was pointed out before,[2] there are several reasons for using this route: (1) The similarity of its technique to that of artificial pneumothorax (the patient is placed in the same position). (2) The availability of the manometer as an indicator; it registers, as a rule, negative pressure as soon as the needle has passed through the parietal peritoneum. (3) The indication of a properly performed injection by the early change of the liver dullness into an area with a tympanitic percussion note. (4) The separation of the liver from the dome of the diaphragm is always gradual, which is not the case when other routes are selected. The advantages of this technique are somewhat lessened by one disadvantage, namely, the possibility of an incidental mediastinal emphysema. In a group of 110 patients whom we treated for pulmonary tuberculosis by artificial pneumoperitoneum, the subphrenic route was used in forty-two instances. Of these, mediastinal emphysema complicated the treatment in seven (16.6 per cent).

The time of the onset of the symptoms of mediastinal emphysema varied from a few minutes to five hours. The symptoms appeared either apparently without any provocation, or by changing from the horizontal position to the upright position while getting off the operating table, or getting out of bed, or by a severe coughing spell. The most prominent symptoms were pain in and about the larynx, choking sensation, and hoarseness. In addition to these some patients complained of stiffness and of soreness in the neck all around, difficulty in coughing and expectorating, dyspnea because of soreness in the neck, pressure sensation in the larynx, pain on swallowing, shoulder pain with or without radiation to one arm, and moderate to severe retrosternal pain (not radiating).

The symptoms began to abate from the twelfth hour to the third day after the onset. Complete relief was observed from twenty-four hours to four days.

The patients, when seen by the physician, appeared to be in moderate discomfort. In some cases slight cyanosis was noted; in others a swelling was found on the anterior aspect of the neck. All but one patient had a palpable interstitial emphysema of the neck. No evidence of emphysema was detectable over the trunk or the extremities.

The treatment consisted of bed rest, sedatives, analgesics, codeine, and in one instance morphine hypodermically.

The following case reports illustrate the course of events:

CASE 1.—A colored male, aged 38 years, had a moderately advanced pulmonary tuberculosis, involving three lobes of the right lung, of three and one-half years' duration. He was receiving artificial pneumoperitoneum treatment by the subumbilical route since Aug. 2, 1937. On Nov. 1, 1937, he was given 1,000 c.c. of air by the subphrenic route on the right side. The initial manometer reading was +10; after 500 c.c. it was +11 on inspiration and +12 on expiration. No final reading was taken because at the end of treatment the patient strained and forced the water out of the manometer. He was able to walk back to his room without difficulty. About

five minutes later he noticed pain, pressure, and stiffness in the neck that was followed by a dull retrosternal pain that did not radiate. It was difficult for him to cough and expectorate, and he was hardly able to swallow. His voice became hoarse, and he had some pain in the right shoulder region. Emphysema in the deep structures of the neck anteriorly was easily detectable by palpation. The roentgenogram of the chest showed a mediastinal emphysema. The symptoms began to abate twelve hours later. Two days later his voice was still slightly hoarse but he was able to swallow and had no more pain, although the air was still palpable along the larynx and in the tissues occupying the anterior cervical triangles. Complete disappearance of all symptoms was noted in four days.

CASE 2.—A white male, aged 20 years, had a moderately advanced pulmonary tuberculosis, involving the right lung, of two and one-half years' duration. He was receiving artificial pneumoperitoneum treatment since Aug. 2, 1937. On Nov. 1, 1937, an attempt was made to inject the air by the subphrenic route, on the left side. Initial manometer readings were +7 and +8 on inspiration and on expiration, respectively. At 500 c.c. the readings were +14 and +16. After 750 c.c. the readings were +18 and +20. About five hours after the treatment he suddenly developed severe retrosternal pain. He stated that because of the pain it was difficult for him to breathe and he could not cough. His voice became hoarse and he had difficulty on swallowing. The physical examination showed a swelling of the anterior aspect of the neck and a palpable emphysema in both anterior cervical triangles. The roentgenogram of the chest revealed a mediastinal emphysema. Symptoms began to subside two days later and disappeared completely in four days.

CASE 3.—A white male had a far-advanced pulmonary tuberculosis of five years' duration involving both lungs. He was receiving pneumoperitoneum treatment since Aug. 9, 1937. The injection was made by the subphrenic route on the left side on Nov. 1, 1937. The initial manometer reading was +5 and +6 on inspiration and expiration, respectively. After 200 c.c. of air was introduced the patient complained of pain and tightness at the site of the injection, which radiated up to the ninth rib and down to the crest of the ileum on the left side. After 850 c.c. was given the manometer reading was +18 and +19. After getting off the operating table the pain eased, and only a dull ache remained. About five hours after the injection, while the patient was up and about, he developed severe retrosternal pain and a choking sensation. He noticed pain on swallowing at the region of the xiphoid process. Coughing produced stinging pain in the left shoulder that radiated down to the middle one-third of the left arm. No palpable emphysema was found on the neck. All symptoms disappeared the following morning. The roentgenogram of the chest showed a mediastinal emphysema. The left parietal pleura lying on the upper surface of the diaphragm was lifted upward and away from the diaphragm by the dissecting air that found its way to the mediastinum by this route.

There were four other patients who developed accidental mediastinal emphysema while on artificial pneumoperitoneum treatment. J. T., No. 7929, white male, aged 45 years, had a far-advanced pulmonary tuberculosis. He was receiving artificial pneumoperitoneum at weekly intervals from Oct. 16, 1933, to Dec. 18, 1933. He developed mediastinal emphysema on this date following the injection of 600 c.c. of air. J. G., No. 8759, white female, aged 24 years, had a far-advanced pulmonary tuberculosis. She was receiving pneumoperitoneum treatment from April 3, 1933, to Dec. 4, 1933. On Nov. 13, 1933, following the injection of 700 c.c. of air by the subphrenic route, typical symptoms and signs of mediastinal emphysema were noted. C. R., No. 8438, white male, aged 39 years, had a far-advanced pulmonary tuberculosis. He was taking pneumoperitoneum from Oct. 16, 1933, to Nov. 13, 1933. On Oct. 23, 1933, following the injection of 325 c.c. of air, presented typical symp-

toms and signs of mediastinal emphysema. N. S., No. 10632, white male, aged 25 years, had a far-advanced pulmonary tuberculosis. He has been on pneumoperitoneum treatment since April 27, 1937. On Nov. 22, 1937, he received 700 c.c. of air by the subphrenic route. Two and one-half hours after this treatment, he began to complain of severe retrosternal pain, hoarseness, pain in the neck, on each side of the trachea and the thyroid cartilage, and of dyspnea.

A palpable emphysema of the neck was easily detectable in these four cases. All responded well to palliative measures and became symptom-free in from one to four days.

Fig. 1. Fig. 2.

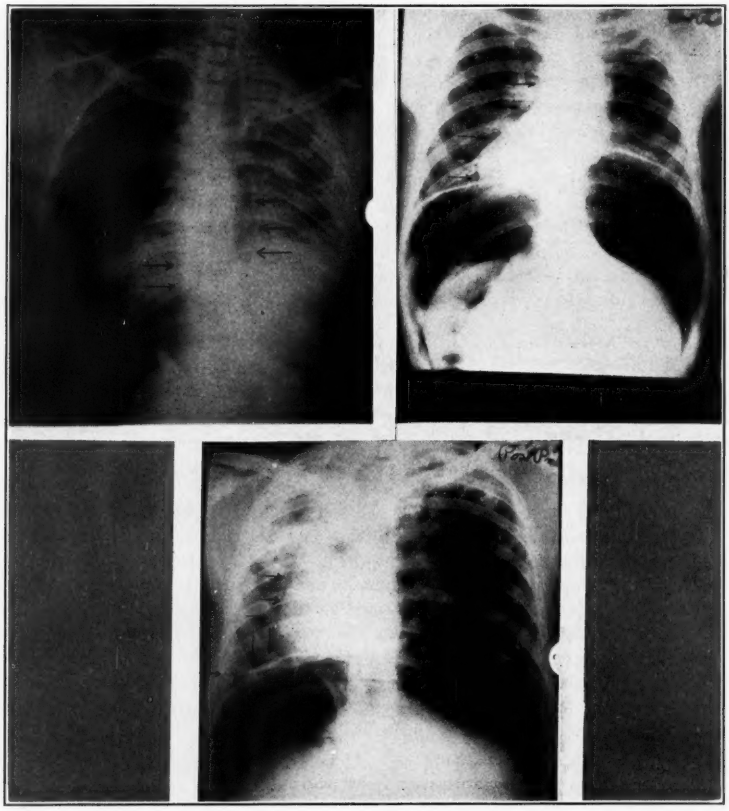


Fig. 3.

Fig. 1.—Case 1. See text for details.
Fig. 2.—Case 2. See text for details.
Fig. 3.—Case 3. Left basal parietal pleura is lifted away from the diaphragm by the dissecting air.

SUMMARY AND CONCLUSIONS

1. Seven cases of mediastinal emphysema that developed during artificial pneumoperitoneum treatment are recorded.

2. While this complication was not observed in patients whom we were treating with pneumoperitoneum by the subumbilical route, it was relatively frequent when the air was injected by the subphrenic route.

3. It is our opinion that the injected air may escape from the peritoneal cavity and may reach the mediastinum in two ways. It may spread along the large blood vessels that are passing through the diaphragm, or along the esophagus. The other possibility is that the air may find its way through the peripheral portion of the diaphragm that might be traumatized with the needle used for the injection. If this is the case, the air elevates the basal parietal pleura, and dissecting it from the upper surface of the diaphragm reaches the mediastinum.

4. The most prominent symptoms were pain in and about the larynx, choking sensation, hoarseness, moderate or severe retrosternal pain, dyspnea, difficulty in coughing and swallowing.

5. Air that escaped from the mediastinum along the trachea was easily palpable in the tissues of the anterior cervical region in six out of seven cases.

6. Roentgenogram is the best means to confirm the diagnosis.

7. Symptoms and signs of mediastinal emphysema disappeared in from one to four days. For the immediate relief of pain and discomfort, analgesics, sedatives or codeine are of value. Morphine hypodermically was necessary in one instance.

8. Because of the likelihood that mediastinal emphysema would recur in these cases if the injections were given by the subphrenic route, it is recommended that the treatment should be continued by the subumbilical route. We have not seen the recurrence of mediastinal emphysema when subsequent injections were given in the left lower quadrant.

REFERENCES

1. Banyai, A. L.: Direct and Indirect Pneumoperitoneum Incidental to Artificial Pneumothorax, Am. J. M. Sc. **186**: 513, 1933.
2. Banyai, A. L.: Therapeutic Pneumoperitoneum. A Review of 100 Cases, Am. Rev. Tuberc. **29**: 603, 1934.

INSTILLATION OF OPAQUE OIL INTO THE BRONCHUS

By Way of a Catheter Passed Through a Naris into the Trachea*

Howard B. Hunt, M.D., and J. Dewey Bisgard, M.D.
Omaha, Neb.

VARIOUS commendable methods for instillation of opaque oil into the bronchi have been devised and are commonly used. Since no one method is universally applicable or entirely satisfactory in all cases it is essential to have a knowledge of and dexterity with a variety of methods. Most commonly used, by virtue of its simplicity and usual efficacy, is the method of Singer. After thorough cocainization of the throat, the tongue is pulled strongly forward and the oil is dropped from a syringe nozzle over the base of the tongue into the larynx while the patient inspires the oil by short quick inspirations and at the same time restrains impulses to cough and swallow. Since the success of the method is dependent upon cooperation from the patient, it cannot be used in children and in very ill and uncooperative adults. Infrequently the oil is swallowed instead of flowing down the trachea and occasionally it is quite impossible to get sufficient oil into the trachea to give adequate delineation of the bronchial tree.

As a simple modification of this method, oil can be instilled into the nasopharynx through the naris either directly or through a short catheter from whence it gravitates into the larynx. This method (the pernasal method) was devised by Forestier and Leroux. The iodized oil, and, previously to it, the anesthetic are deposited with an ordinary syringe on the floor of the naris while the patient's head is lifted sufficiently to cause the solutions to gravitate into the pharynx. They are made to flow into the larynx by maintaining traction upon the protruded tongue during injection. They state that, "when the tongue is pulled out of the mouth and grasped firmly, the epiglottis is raised with the whole larynx, the upper orifice of the esophagus is closed, and the patient is unable to swallow." In common with the Singer method this modification demands cooperation from the patient and is limited by inability to direct the oil with absolute precision into the trachea and into all parts of the bronchial tree. To accomplish this end with certainty, the oil must be deposited either under visual control or subglottically. Visual control can be directed with a laryngeal mirror or through a laryngoscope, but by reason of technical difficulties the procedures are little used by surgeons and radiologists who are most commonly confronted with the problem of bronchography.

*From the Departments of Radiology and of Surgery in the University of Nebraska College of Medicine, Omaha.

Received for publication June 2, 1937.

The transcricoid injection of oil has certain theoretic if not actual objectionable features. Often some of the oil is deposited outside of the trachea and can be demonstrated roentgenographically in the cervical fascial spaces. Not infrequently air escapes from the puncture wound in the trachea and dissects along the fascial spaces and subcutaneously, sometimes over a wide area.

By all of the above methods filling of the upper lobe bronchi is often meager or impossible because such filling depends upon gravitation of the oil, with posture, from the bronchi of the filled lower lobes into those of the upper lobes.

In our experience the most definitive, infallible, and satisfactory filling of both upper and lower lobe bronchi has followed instillation of oil through a catheter indwelling the trachea, as proposed by Hicquet and Hennebert, of Brussels. Not infrequently we have experienced difficulty in threading the catheter into the trachea and to overcome this we have used the simple procedure which is illustrated in Fig. 1. A small catheter is introduced through a naris, and as the tip appears in the pharynx it is caught with a hook, by means of which it is pulled forward against the back of the tongue, and then under fluoroscopic control it is easily threaded through the larynx into the trachea. The technique in detail follows.

After preliminary sedation of codeine gr. 1 ss. or morphine gr. $\frac{1}{6}$ to $\frac{1}{4}$, the patient empties his bronchi as thoroughly as possible by postural drainage with the head and shoulders tipped downward in a dependent prone position.

The radiographic units, including the fluoroscope, are made ready for immediate use. The film is placed and the exposure is predetermined to allow immediate exposure after instillation of the oil before it has been retracted into the alveoli. Breakfast is omitted.

To gain the patient's confidence the procedure is explained step by step before it is started, and he is assured that there is absolutely no danger of choking regardless of such sensations and apprehension which may develop during the procedure. He is asked to exert every effort to refrain from coughing which may expel the catheter and scatter the oil and from swallowing, and is instructed to take short, even breaths through the mouth. He is told that he may feel the oil trickle down the trachea and not to permit it to alarm him.

The following instruments and materials are at hand: (1) Sterile instruments and goods; 20 c.c. syringe with catheter adapter, soft rubber catheters, sizes 14, 16, 18, a flexible wire hook, two medicine glasses, 2 c.c. syringe with hypodermic needle, laryngeal mirror, throat applicators, tongue blades, six flat dressings, two towels. (2) Drugs: Cocaine hydrochloride, 10 per cent solution or pontocaine 2 per cent, epinephrine, 1 ampoule, iodized oil, 20 c.c. container, sterile olive oil,

quart basin with hot water at 120° F. (3) Accessories: head lamp or head mirror, atomizer containing 10 per cent cocaine solution or pontocaine 2 per cent, emesis basin, gown, two stools, alcohol lamp.

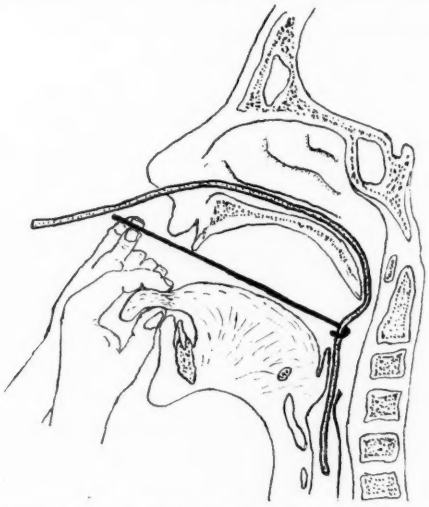


Fig. 1.—Diagram showing course of catheter and its control and direction by means of a wire loop.

Good anesthesia is an absolute prerequisite to successful instillation of oil by any method. The naris and throat are sprayed repeatedly over a period of at least ten minutes with a solution of 10 per cent cocaine or 2 per cent pontocaine by means of an atomizer. Inspiration during insufflation carries some of the anesthetic solution into the tracheal tree. By this method there is no danger of swallowing significant amounts of the drug. This is important because absorption from the stomach is much more rapid than from the trachea, and a correspondingly smaller dose in the stomach will give toxic symptoms. When taken into the stomach, 2 to 5 c.c. of a 10 per cent solution of cocaine may prove fatal. Pontocaine is much less toxic. Epinephrin is at hand for treatment of an acute reaction to cocaine, should it develop. The iodized oil should be heated to about 120° F. to allow for cooling during filling of the syringe and during injection.* Since lipiodol is quite dense it retains adequate radiopacity even after dilution with an equal quantity of olive oil. The diluted oil floats on top of the pus, while undiluted lipiodol sinks. The other brands of halogenized oil are less opaque and permit little or no dilution.

*Oil and syringe can be effectively heated by cautiously passing loaded barrel across an alcohol flame. The lipiodol (Lajay) referred to has 40 per cent iodine content. Topical anesthesia of the inferior aspect of the tongue will facilitate forward traction during instillation by lessening discomfort from pressure of teeth against the tongue.

The patient is then placed on a stool before the fluoroscope and is again familiarized with the procedure.

A catheter, usually size 16, is inserted into a naris and passed backward below the inferior turbinate into the pharynx. Passage into the middle meatus or beneath the middle turbinate will usually meet obstruction. The patient turns his head to the left to allow fluoroscopic observation of the position of the catheter in the nasopharynx.

Fig. 2.—Fluoroscopic portrayal of the catheter properly placed for injection.

The tongue is pulled firmly forward out of the mouth and the patient is instructed to inhibit swallowing. Instillation may be carried out successfully at this stage if there is no swallowing of oil. In case difficulty is encountered or anticipated, the catheter is then threaded through the pharynx and into the trachea under fluoroscopic control. This is facilitated by a forward tilt of the neck and elevation of the chin. If the catheter persists in entering the esophagus, as it often does, it is withdrawn until it can be grasped with a loop made from a long flexible applicator and shaped like a buttonhook as shown in Fig. 1. With it the tip of the catheter is drawn forward above the glottis.

Now by turning the body of the patient in a nearly direct lateral position, manipulations can be better controlled due to fluoroscopic portrayal of the trachea, the pharynx, and the catheter in one plane. The catheter guided by the loop and by fluoroscopic vision is made to pass just behind the epiglottis and threaded between the vocal cords into the trachea. As soon as the catheter is placed at the desired level in the trachea, an assistant immediately winds a narrow strip of adhesive about the catheter and firmly anchors it to the nose. The patient

is asked to breathe evenly and to avoid coughing. The catheter in situ is surprisingly well tolerated. The assistant attaches the syringe filled with warm opaque oil to the catheter and all is ready for the instillation.

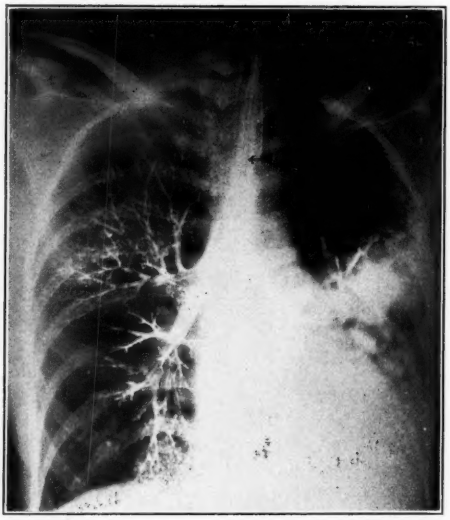


Fig. 3.—Filling of all lobes of the right lung by way of an intratracheal catheter. A previous filling of both left lobes had demonstrated bronchiectasis confined to the left lower lobe.

The entrance and distribution of oil in the bronchial tree are observed fluoroscopically by the examiner while his assistant gradually empties the syringe and manipulates the patient. In case delineation of the bronchi to only the lower lobes is desired, about one-half of the oil is put in with the patient erect to fill the right bronchus and one-half with the patient tilted to the left at about 20° to fill the other side. In case filling of an upper or middle lobe bronchus is desired, the catheter can be passed down to the tracheal bifurcation or passed alternately into the stem bronchi so that the tip lies directly opposite the branch bronchus to be filled, and the patient is tilted or placed horizontally into the lateral or posterior oblique position with the side to be injected inferiorly placed. The resulting roentgenogram after such a procedure of instillation is shown in Fig. 3. It is essential to be prepared to make roentgenograms with the patient in a recumbent posture immediately upon completion of instillation of oil into the upper lobes.

The roentgenograms found most helpful vary with the case. The posteroanterior or anteroposterior projections are always necessary. When only one side is injected, a lateral projection is very valuable. When both sides are injected, which is most usual, right and left

oblique projections are indicated. The oblique projections are particularly helpful in differentiation between the superimposed structures of the upper and lower lobes. The exposure used following injection of opaque oil should be about 50 per cent heavier than the factors used for a plain roentgenogram of the particular chest.

SUMMARY

1. A simple and effective procedure for the intratracheal instillation of opaque oil by way of a small catheter passed through a naris and down the trachea is described. A loop or hook for use in directing the tip of the catheter into the larynx can be made simply from a flexible wire applicator.

2. Fluoroscopic observation is readily carried out during the time of instillation to permit diagnostic observations and directive manipulations.

3. The procedure allows the injection of any portion of the bronchial tree with a high degree of precision.

REFERENCES

1. Forestier, J., and Leroux, L.: A Simplified Method of Bronchography, Radiology **24**: 743, 1935.
2. Hicquet, G., and Hennebert, P.: La bronchographie au lipiodol par voie transnasale, procédé de Hicquet et Paul Hennebert, Arch. méd-chir. de l'app. respir. **10**: 304, 1935.

AN UNUSUAL COMPLICATION OCCURRING DURING THORACOPLASTY

ARCHIBALD R. JUDD, M.D.
GLEN GARDNER, N. J.

A SURVEY of the literature has failed in locating a similar complication occurring during the course of an extrapleural thoracoplasty. Discussion of the case with several thoracic surgeons warrants the conclusion that a report of this interesting situation is justified.

CASE REPORT

The patient (A. C.) had an active tuberculous, cavernous lesion of the right lung, confined principally to that area above the fourth rib posteriorly. His sputum was positive and attempts to control it by pneumothorax and hemidiaphragmatic paralysis were unsuccessful. A thoracoplasty had been advised by the medical conference, and the first stage had been performed with removal of the first rib and a portion of its cartilage, the second rib to within 3 to 4 cm. of its costochondral junction, and the third rib to within 5 to 7 cm. of the costochondral junction of that rib. The periosteal beds were thoroughly formalinized with 10 per cent formalin. Following this operation the patient's cough and sputum decreased to practically complete absence, but whatever sputum he had remained positive for acid-fast bacilli on concentrated twenty-four-hour specimens. Repeated x-ray examinations, including those taken with the Potter-Bucky screen, failed to show definite residual cavities. A bronchoscopic examination was considered advisable to eliminate the possibility of a bronchial lesion. This examination showed the bronchi and trachea normal; but a lipiodol pneumonography showed a series of bronchiectatic cavities at the level of the fourth to the fifth ribs posteriorly. A second stage was then decided upon and performed as soon as possible. It was during the course of this operation that the complication herein described was encountered.

The patient was placed upon the operating table in the usual position for a paravertebral thoracoplasty.* Nitrous oxide-oxygen anesthesia was used. The incision was made by removing the scar of the previous first stage and carrying it deep through the intervening layers to the outer surfaces of the ribs. The area of the first operative field was explored and no regenerated bone found. In addition to a portion of the remaining stump of the third rib, 13 to 15 cm. of rib four were resected subperiosteally as were 14 to 17 cm. of rib five. As the transverse vertebral processes were being resected the patient developed a deep "snoring sound" accompanied by severe paradoxical motion of the decostalized area. This resulted in a powerful stress being exerted along the line of the superior surface of the sixth rib. As the anesthetist was attempting to handle the situation, a sudden deep hollow sound was heard as the entire lung had given way in the plane of the endothoracic fascia, extending from the point of operation above to within about 5 cm. of the

From the New Jersey Sanatorium, Glen Gardner, N. J.
Received for publication March 8, 1938.

*Alexander, J.: The Collapse Therapy of Pulmonary Tuberculosis, p. 471, Springfield, Ill., 1937, Charles C. Thomas, Publisher.

diaphragm below, to the posterior vertebral gutter behind, and the mediastinum at the sternum in front. The whole complex seemed to occur in less than a minute, although the actual time could not be determined because, naturally, no such situation was foreseen. This accident was definitely extrapleural and not a mere collapse of the lung due to the opening of an unobliterated pleural cavity.

There was no appreciable change in the patient's condition, and no bleeding points opened up. An increase in the oxygen intake decreased the patient's respirations; the lung remained at about a 70 per cent collapsed condition, and there still persisted a small amount of paradoxical movement. As the patient's condition was quite satisfactory, a few moments were taken to complete necessary details of the operation, to determine definitely the anatomic relationships, and to ascertain that we were actually dealing with an extrapleural phenomenon. The wound was then closed in the following manner, as the anesthetist was unacquainted with the technique necessary for reinflating the lung: The deep layers of the wound were closed in part, care being exercised that there was free ingress and egress of air at all times. As the lower pole of the wound was approached a rubber tube was inserted and a purse-string suture laid around it. The closure was then made airtight, and an assistant then aspirated the air from the residual space through the tube. After the maximum quantity of air had been withdrawn, the purse-string suture was cinched down as the tube was withdrawn. This procedure almost completely re-expanded the lung and left no opportunity for a tension pneumothorax to develop. The operation was completed, and the patient was returned to bed in good condition, when intravenous 5 per cent glucose was started.

The convalescent period was uneventful, the temperature and pulse remained within the usual postoperative limits at all times. Postoperative x-ray films, however, showed a moderate accumulation of fluid which absorbed spontaneously, no aspiration being necessary as the patient remained asymptomatic. At the present time his condition is very satisfactory. His sputum has been free from tubercle bacilli since the operation. He has gained approximately fifty pounds, and is now doing light work.

A THORACOPLASTY BRACE*

JOHN D. STEELE, JR., M.D.
MILWAUKEE, WIS.

THE purpose of a brace for use following extrapleural thoracoplasty is to produce added compression and to stabilize the thoracic wall until rib regeneration has progressed sufficiently to effect permanent stabilization.

The brace is designed to effect maximum compression and stabilization with the greatest possible simplicity in construction. An anterior pad and a posterior pad are connected by a steel spring passing over the shoulder. The anterior pad is constructed of layers of firm sponge rubber cemented together. The size of this pad must be varied according to the size of the patient and the thickness according to the amount of compression desired. For a patient of average size this pad should measure 4 inches by 2¾ inches and should be approximately 1½ inches thick. The posterior pad consists of a sheet of softer sponge rubber ½ inch in thickness. Both pads are attached to metal plates and are covered with canton flannel. The spring is tempered steel, ¾ inch in width and ⅛ inch thick. It is covered by a removable leather sheath. Two 3/16-inch stove bolts, 1½ inches in length, are welded to the metal plate of the anterior pad. These pass through holes in the anterior end of the spring and are locked to it by nuts. The posterior end of the spring is riveted to the metal plate of the posterior pad.

The pressure of the brace is altered by changing the distance between the anterior pad and the spring. The tilt of this pad is also adjustable. Daily adjustments are not necessary.

The brace is held in place by straps, consisting in part of elastic tape, which run to a felt band passing beneath the arm on the opposite side of the thorax (Figs. 2, 3, and 4).

It is our practice to have the brace constructed following the first stage of the thoracoplasty, and to have the patient begin to wear it at this time. Adjustments must be made subsequently as the thoracoplasty is continued. When the scapula drops forward, a further and final adjustment of the posterior pad becomes necessary. This is accomplished by inserting the posterior end of the spring in a vise, after removal of the leather sheath, and bending the pad forward.

Appreciable collapse is produced by the brace even when the anterior stumps and cartilages of the upper ribs remain unresected. Con-

*From the Department of Surgery, University of Michigan. The preparation of this report was aided by the Dr. George Alexander Fleming Memorial Fund for Thoracic Surgery.

Received for publication September 15, 1937.

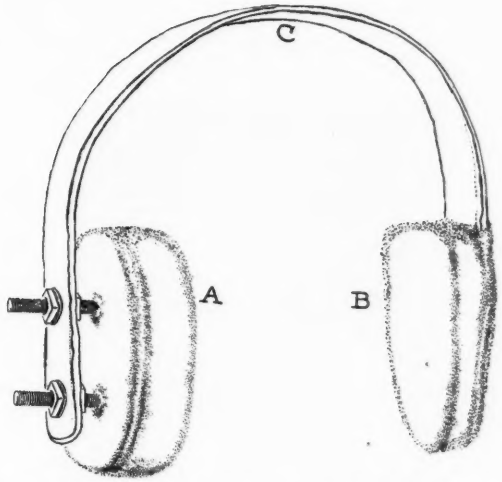


Fig. 1.—Diagram of brace without straps. *A*, anterior pad; *B*, posterior pad; *C*, tempered steel spring.

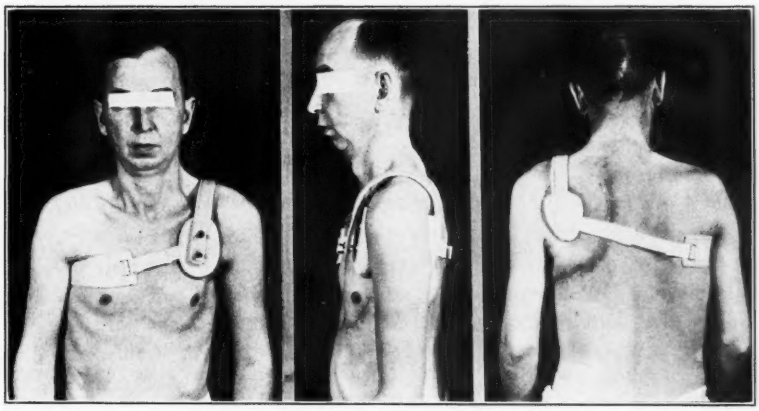


Fig. 2. Fig. 3. Fig. 4.

Fig. 2.—Anterior view of brace in position.
Fig. 3.—Lateral view of brace in position.
Fig. 4.—Posterior view of brace in position.

siderably more collapse is obtained when the upper anterior costal stumps have been resected and the cartilages divided parasternally. Maximum compression is obtained after resection of both cartilages and costal stumps. Stabilization of the anterior thoracic wall is effected by the brace in any case.

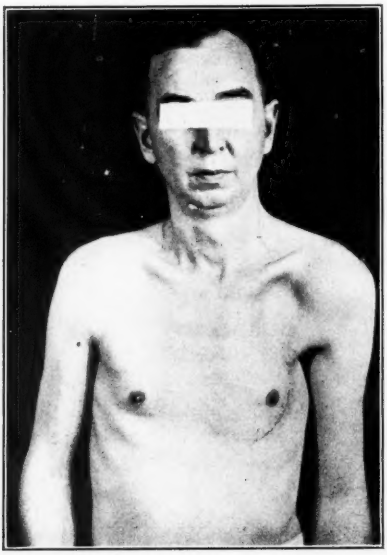


Fig. 5.—Subclavicular depression produced in part by brace following eight-rib posterior thoracoplasty and complementary anterior thoracoplasty (Haight[2]).

The effect of the brace is limited to anteroposterior compression of the upper thorax. Lateral compression, as well as compression of the lower thoracic wall, is obtained by having the patient lie over a folded pillow on the operated side according to the method described by Bisgard.[1]

Previous to our adoption of this brace, we had been using the one described by Woodruff.[3] The greater simplicity in construction and application and the increased efficiency of the new brace influenced us in making the change.

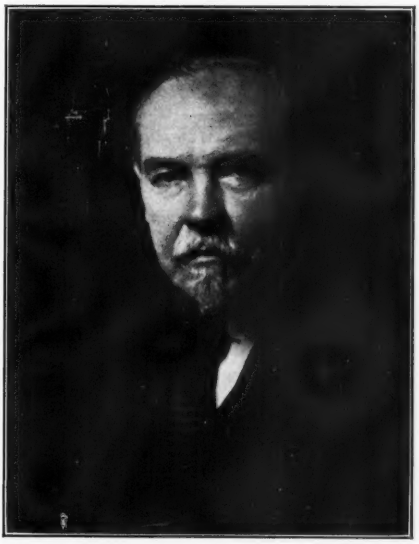
REFERENCES

1. Bisgard, J. D.: Postural Wedge Compression of Thorax; Aid to Maximal Collapse, Prevention of Scoliosis and Visualization of Possible Residual Cavity After Thoracoplasty, J. THORACIC SURG. 3: 99, 1933.
2. Haight, C.: Complementary Anterior Thoracoplasty for Pulmonary Tuberculosis, J. THORACIC SURG. 5: 453, 1936.
3. Woodruff, W.: Description of a Thoracoplasty Brace, J. THORACIC SURG. 2: 99, 1932.

In Memoriam

FRANZ J. A. TOREK
1861-1938

In the death of Dr. Franz Torek, on Sept. 19, 1938, the American Association for Thoracic Surgery lost one of its most prominent members. He joined the Association as a founder member in 1917, became its vice-president in 1926, and president in 1927. In 1936 the Association conferred honorary membership upon him.



Franz J. A. Torek

Like the great majority of the members of our Association, Dr. Torek was a general surgeon with a special interest in thoracic surgery. He published several papers dealing with different phases of our specialty. His outstanding contribution, however, was the first successful resection of the thoracic portion of the esophagus for carcinoma by a method he himself had developed. The principles of this operation have been recognized as fundamental and are being followed today throughout the world.

Dr. Torek was a versatile general surgeon. There is no field of surgery into which he did not venture and to which he did not make

some worth-while contribution. Especially, operations requiring technical skill interested him, and this is evident in his writings. The different procedures he developed were always the result of careful planning and practice on the cadaver. His approach to a difficult surgical problem was likewise one of detailed planning; then he executed it with an ease and skill which made it appear almost simple. His unusual talents found their greatest application in his treatment of cancer, in which his patience, his deftness, and his courage were of inestimable value. Although his publications in this field are limited, it is perhaps principally for his radical cancer operations that he will be remembered by those who were associated with him. His chief service to the public lies in the relief or cure afforded innumerable sufferers from cancer. His service to the profession may be measured by his stimulation of the many young surgeons who worked with him, to perform good cancer surgery.

In the treatment of his patients he embodied all the virtues of a great surgeon, for he had sympathetic understanding of their mental as well as their physical suffering and he had the courage and daring to do what was necessary to enable them to become well.

As the result of his unusual qualifications, his activities were not limited to one institution. After graduating from the College of Physicians and Surgeons, he served an internship at the German Hospital, now the Lenox Hill Hospital, and remained connected with it until his death, a period of over fifty years. He was a member of the attending staff of the New York Post Graduate Hospital from 1890 to 1915, when he resigned after twenty-five years of service. He was attending surgeon at St. Mark's Hospital from 1891 to 1905. The history of the New York Skin and Cancer Hospital is closely interwoven with the name of Dr. Torek, for he served on the attending staff from 1890 to 1935, during almost the entire period of independent existence of that institution. After it became merged with the New York Post Graduate Hospital he was appointed consulting surgeon.

He was a member of leading medical and surgical societies, including the New York Surgical Society, the American Surgical Association, the New York Society for Thoracic Surgery, the American Association for Thoracic Surgery, and the German Medical Society. He was an ex-president of the three latter organizations.

Dr. Torek was born April 14, 1861, in Breslau, Germany. At the age of 11 years he came to America with his parents and attended the public schools and later the College of the City of New York; he graduated at the age of 19 years. He was elected to Phi Beta Kappa. After teaching English for several years, he studied medicine at the College of Physicians and Surgeons, and received the degree of M.D. in 1887.

He had a musical background and was himself an accomplished musician, which contributed much to enrich his life.

He is survived by his wife, the former Minnie Volkening, and a son and daughter, as well as several grandchildren.

He was a quiet, thoughtful, modest man. Kind and sympathetic, he endeared himself to all those with whom he came into contact.

Because of his personality, his sterling character, his work and his contributions, Dr. Torek will long be remembered and be an inspiration to those who follow after. He was a real surgeon.

Carl Eggers.

Book Reviews

ON THE TECHNIQUE OF PNEUMONECTOMY IN MAN, A CRITICAL SURVEY OF THE EXPERIMENTAL AND CLINICAL DEVELOPMENT AND A REPORT OF THE AUTHOR'S MATERIAL AND TECHNIQUE. By Clarence Crafoord. Tryckeri Aktiebolaget Thule, Stockholm, 1938.

This monograph of 142 pages in English from Giertz's clinic of the Sabbatsberg Hospital, Stockholm, is a most important contribution to the subject of pneumonectomy. The part which will probably make the greatest appeal to American thoracic surgeons is that which deals with Crafoord's incision and method of handling the hilar structures. The reviewer who has used it himself in five cases can testify to its great superiority over either an anterior or a posterior incision. Its great advantage lies in the excellent exposure which it provides and the accessibility to the hilar structures which can be approached from either an anterior or posterior direction.

The incision begins at the level of the transverse costal joint of the fourth rib about 7 to 8 cm. from the posterior midline. It is then carried parallel to the spinous process to a point 3 to 4 cm. below the angle of the scapula. It swings around the angle of the scapula and up toward the mid-axillary line to the level of the fifth rib from where it runs downward and forward along this rib to the costal cartilage. The underlying muscles are divided. The scapula is lifted up from the chest wall by coarse silk threads passed through the soft tissues at the angle. The fifth rib is removed throughout its whole length.

The author has used his method in sixteen cases, of which twelve were for malignant and four for nonmalignant disease. Six of the patients were alive from three months to two years.

He ligates the vessels separately and closes the bronchus with an invaginating suture reinforced by a second layer of sutures. He emphasizes the importance of a method of anesthesia which permits adequate pulmonary ventilation by rhythmical injection of air into the trachea followed by free outflow, and he uses a special apparatus for this purpose. For anesthesia he prefers nitrous oxide reinforced, if necessary, by cyclopropane.

There is an excellent review of the literature of pneumonectomy and an interesting discussion of many of the technical points. The work is strongly recommended by the reviewer to all thoracic surgeons.

Evarts A. Graham.

LAS NEUMECTOMIAS TOTALES. By Jorge A. Galarce. Doctorate thesis of the School of Medicine of the University of Buenos Aires. Published by "El Ateneo," Buenos Aires, 1937. 309 pages.

This monograph gives an excellent review of the literature of total pneumonectomy. The author advises the use of different techniques for pneumonectomy in septic and aseptic conditions respectively. In the former conditions he advises against the use of preliminary pneumothorax because of a greater danger of an infection of the pleural cavity and the opposite lung. In the latter he advises a preliminary pneumothorax. In septic cases he advises a posterolateral incision without dissection of the hilar structures, using intratracheal anesthesia with suction and blocking of the bronchus of the affected lung. In aseptic cases, however, he recommends an anterior incision under local and regional anesthesia with individual treatment of the different components of the hilus.

Evarts A. Graham.

Special Notice

The JOURNAL is restricted to approximately 672 pages a year. For that reason it is difficult to accept for publication articles that are long or that are profusely illustrated. Authors should avoid the inclusion of unnecessary or irrelevant details of cases. Attempts should be made to be as brief as is consistent with a clear statement of the points to be covered. Grouping of illustrations will make it possible to publish more than if they are sent as single ones. The editor cannot take it upon himself to do the grouping for authors. In general, articles of less than five thousand words with not more than five or six illustrations will be given preference over longer ones or those more profusely illustrated.

The American Association for Thoracic Surgery

Officers

PRESIDENT, HAROLD BRUNN, San Francisco, Calif.
VICE-PRESIDENT, ADRIAN V. S. LAMBERT, New York, N. Y.
SECRETARY, RICHARD H. MEADE, JR., Philadelphia, Pa.
TREASURER, I. A. BIGGER, Richmond, Va.
EDITOR, EVARTS A. GRAHAM, St. Louis, Mo.

Council

STUART W. HARRINGTON, Rochester, Minn. FRANK S. DOLLEY, Los Angeles, Calif.
FRANK B. BERRY, New York NORMAN BETHUNE, Montreal, Canada
DAN C. ELKIN, Atlanta, Ga.

The 1939 Meeting of the American Association for Thoracic Surgery

Notice to Members

The dates for the meeting in Los Angeles have been changed to July 5, 6, and 7. This change was made because of the discovery that our original dates exactly coincided with those for the meeting of the National Tuberculosis Association. It had been previously understood that no such conflict existed.

Headquarters for the meeting will be the Hotel Ambassador. Information in regard to reservations will be furnished by the hotel. Dr. Frank Stephen Dolley is chairman of the Local Committee on Arrangements.

"Tumors of the Lung" has been chosen as the principal subject for discussion at the meeting, and it is hoped that a sufficient number of papers will be offered the Program Committee to allow for the arrangement of a well-cordinated symposium. Members are reminded that the closing date for acceptance of papers will be March 15. Titles and short abstracts should be sent to the Secretary as soon as possible.

RICHARD H. MEADE, JR.,
Secretary.